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Optical, Chemical, and Biological Oceanographic Conditions in the Maritimes Region in 2009 and 2010

Propriétés optiques, chimiques et biologiques de l'océan dans la région des Maritimes, en 2009 et 2010

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ABSTRACT

Optical, chemical, and biological oceanographic conditions in the Maritimes Region (Georges Bank, eastern Gulf of Maine, Bay of Fundy, and the Scotian Shelf) during 2009 and 2010 are reviewed and related to conditions during the preceding year and over the longer-term, where applicable. In addition to descriptions of Atlantic Zonal Monitoring Program (AZMP) core data collections (fixed stations, seasonal sections, ecosystem trawl or groundfish surveys, remote-sensing), some data from outside the region are discussed also to provide the larger, zonal perspective.

Optical properties at the Maritimes fixed stations in 2009 and 2010 differed by site but were, for the most part, comparable to conditions observed in previous years.

Winter-time nutrient inventories in surface waters at Halifax-2 were normal in 2009 but slightly below average in 2010; inventories were higher than normal in 2009 and 2010 at Prince-5. Deep (>50 m) nutrient inventories in spring were lower than normal in the Emerald Basin and off the western Shelf in 2010 but were higher than normal in summer. Overall, annual nutrient anomalies were at record high levels in 2009 and near record low levels in 2010 in Maritimes waters.

The seasonal growth cycle of phytoplankton in the Maritimes Region 2009 was unremarkable, i.e. similar to conditions seen previously. In 2010, however, the spring bloom started much earlier than usual and was similar to the conditions seen in 1999 when AZMP started. 2010 may be a strong year-class for both cod and haddock, as 1999, based on preliminary data analysis. Phytoplankton community structure at the two fixed stations in 2009 and 2010 was similar to that seen in previous years with diatoms dominating during the spring bloom and flagellates dominating in summer-fall at Halifax-2 and diatoms dominating the community at Prince-5 year-round. The relative abundance of ciliates increased at both stations in 2009 and 2010. Overall, annual phytoplankton anomalies suggested conditions were near normal in 2009 and 2010 despite the early spring bloom in 2010.

Annual zooplankton anomalies were lower than normal in 2009 and near normal in 2010, and the timing of the seasonal biomass peak was normal or near normal in both years. The abundance of the dominant copepod *Calanus finmarchicus* and of total copepods were lower than normal throughout most 2010 at Halifax-2, but both exhibited strong peaks in April and June. Zooplankton biomass and abundance anomalies were spatially variable in 2010, with higher values in the Cabot Strait and Eastern Scotian Shelf.

The unusually low NAO in 2010 may portend environmental changes in 2011-2012.

RÉSUMÉ

On examine les conditions océanographiques optiques, chimiques et biologiques dans la région des Maritimes (banc Georges, est du golfe du Maine, baie de Fundy et plate-forme néo-écossaise) au cours de 2009 et de 2010, puis on les compare aux conditions observées au cours de l'année précédente et à long terme, s'il y a lieu. En plus des descriptions des séries de données de base du Programme de monitorage de la zone atlantique (PMZA) (stations fixes, transects saisonniers, relevés au chalut de l'écosystème ou du poisson de fond, télédétection), on examine un certain nombre de données de l'extérieur de la région afin de donner une vue d'ensemble de la zone.

Les propriétés optiques aux stations fixes de la région des Maritimes en 2009 et en 2010 différaient d'un endroit à l'autre, mais en général, étaient comparables aux conditions observées les années précédentes.

Au cours de l'hiver, les concentrations d'éléments nutritifs dans les eaux de surface à Halifax 2 se situaient à des niveaux habituels en 2009, mais étaient légèrement en dessous de la moyenne en 2010; les concentrations d'éléments nutritifs étaient supérieures à la normale en 2009 et en 2010 à Prince 5. Les concentrations d'éléments nutritifs en profondeur (plus de 50 m) au printemps étaient plus faibles que la normale dans le bassin d'Émeraude et à l'ouest de la plate-forme en 2010, mais étaient supérieures à la normale en été. Dans l'ensemble, les anomalies annuelles relatives aux éléments nutritifs étaient à des niveaux élevés records en 2009 et à des niveaux bas presque records en 2010 dans les eaux de la région des Maritimes.

Le cycle de croissance saisonnière du phytoplancton dans la région des Maritimes en 2009 était anodin, c'est-à-dire qu'il était semblable aux conditions observées précédemment. En 2010, cependant, l'efflorescence printanière a commencé beaucoup plus tôt que d'habitude et était semblable aux conditions observées en 1999 au commencement du Programme de monitorage de la zone atlantique. L'année 2010 peut représenter une forte classe d'âge pour la morue et l'aiglefin, comme en 1999, si l'on tient compte de l'analyse des données préliminaires. La structure de la communauté du phytoplancton aux deux stations fixes en 2009 et en 2010 était semblable à celle observée au cours d'années précédentes avec la domination de diatomées au cours de l'efflorescence printanière, de flagellés au cours de l'été et de l'automne à Halifax 2 et de diatomées dans la communauté à Prince 5 toute l'année. L'abondance relative de ciliés a augmenté dans les deux stations en 2009 et en 2010. Dans l'ensemble, les anomalies annuelles relatives au phytoplancton ont laissé entendre que les conditions étaient presque normales en 2009 et en 2010, malgré le début précoce de l'efflorescence printanière en 2010.

Les anomalies annuelles relatives au phytoplancton étaient inférieures à la normale en 2009 et presque normales en 2010, et la période de biomasse maximale saisonnière était normale ou presque normale au cours des deux années. L'abondance du copépode dominant *Calanus finmarchicus* et la quantité totale de copépodes étaient inférieures à la normale presque tout au long de l'année 2010 à Halifax 2, mais elles ont connu des pics importants en avril et en juin. Les anomalies relatives à la biomasse et à l'abondance du zooplancton étaient variables sur le plan spatial en 2010, avec des valeurs plus élevées dans le détroit de Cabot et à l'est de la plate-forme néo-écossaise.

L'oscillation nord-atlantique anormalement basse en 2010 peut présager des changements environnementaux en 2011-2012.

INTRODUCTION

The Atlantic Zonal Monitoring Program (AZMP) was implemented in 1998 (Therriault et al. 1998) with the aim of: (1) increasing Department of Fisheries and Oceans' (DFO's) capacity to understand, describe, and forecast the state of the marine ecosystem and (2) quantifying the changes in ocean physical, chemical, and biological properties and the predator-prey relationships of marine resources. A critical element in the observational program of AZMP is an annual assessment of the distribution and variability of nutrients and the plankton they support.

A description of the distribution in time and space of nutrients dissolved in seawater (nitrate, silicate, phosphate, oxygen) provides important information on the water-mass movements and on the locations, timing, and magnitude of biological production cycles. A description of the distribution of phytoplankton and zooplankton provides important information on the organisms forming the base of the marine foodweb. An understanding of the production cycles of plankton is an essential part of an ecosystem approach to fisheries management.

The AZMP derives its information on the state of the marine ecosystem from data collected at a network of sampling locations (fixed point stations, cross-shelf sections, trawl surveys) in each DFO region (Quebec, Gulf, Maritimes, Newfoundland) sampled at a frequency of bi-weekly to once annually. The sampling design provides for basic information on the natural variability in physical, chemical, and biological properties of the Northwest Atlantic continental shelf. Trawl (groundfish) surveys and cross-shelf sections provide detailed geographic information (Harrison et al. 2005), but are limited in their seasonal coverage. Critically placed fixed stations complement the geography-based sampling by providing more detailed information on temporal (seasonal) changes in ecosystem properties.

Reviewed here are the optical, chemical, and biological oceanographic (lower trophic levels) conditions in the Maritimes Region, including the Georges Bank/Gulf of Maine/Bay of Fundy system and the Scotian Shelf, during 2009 and 2010. Conditions will be compared with those observed during recent years and over the longer-term where historical information is available.

METHODS

To the extent possible, sample collection and processing conforms to established standard protocols (Mitchell 2002). Non-standard measurements or derived variables are described.

Sample Collection

Maritimes/Gulf AZMP sea-going staff participated in 6 missions (seasonal section cruises and trawl surveys) during the 2009 and 2010 calendar years, in addition to repeat day-trips to the 3 fixed stations. In 2009, a total of 609 station occupations were performed, while in 2010, 584 station occupations were performed by Maritimes Region (Table 1).

Fixed stations. The Maritimes/Gulf regions' 3 fixed stations, Shediac Valley, Halifax-2, and Prince-5 (Figure 1), were sampled on a minimum monthly basis (Prince-5) with attempted semi-monthly sampling during the spring bloom period. As always, the availability of sampling platforms and, to some extent, difficulties with weather and ice, make achieving this sampling frequency a challenge. In 2009, Halifax-2 and Prince-5 were sampled on 19 and 12 occasions, respectively. Shediac was sampled only 7 times. In 2010, Halifax-2 and Prince-5 were sampled on 18 and 12 occasions, respectively. Shediac was again sampled 7 times. Fixed station occupations were, once again, below the highest frequency in 2002. By definition, the Shediac

station has an ice-truncated open water season. Difficulties encountered with Coast Guard operations and platform availability in the previous years have been resolved somewhat, and the number of Shediac station occupations was consistent with those of recent years.

The standard sampling suite when occupying the fixed stations consists of:

- CTD (Conductivity, Temperature, Depth) (SBE25) profile including electronic sensing of pressure, temperature, conductivity, dissolved oxygen, fluorescence, and PAR (Photosynthetically Active Radiation) as the common suite of measurements,
- Niskin water bottle samples at standard depths for nutrient, calibration salinity, calibration oxygen, and chlorophyll analyses as the minimum suite,
- Niskin water bottle sample for phytoplankton enumeration,
- Vertical ring net tows (202 and 76 µm mesh net) for zooplankton biomass (wet weight) and enumeration, and
- Secchi depth measurement when possible.

Shelf sections. Four primary transects (Browns Bank Line, Halifax Line, Louisbourg Line, Cabot Strait Line; Figure 1), and a number of additional lines/stations (Figure 2) are sampled seasonally in spring (April/May) and fall (October/November). An additional occupation of the Halifax Line is also attempted in May-July period as part of the Labrador Sea program in the Maritimes Region. In **2009**, the normal/full sampling campaigns for the spring and fall missions were carried out from the *CCGS Hudson*. The 4 core transects were occupied in both seasons. There was an opportunity to sample the Halifax Line in May 2009, as the field-time allotted to the Labrador Sea mission allowed sufficient time to occupy the section. While five new deep-water stations added to the Halifax line were sampled at that time, two inshore stations, including the high priority 'fixed station' HL2, were not occupied. In **2010**, the normal/full sampling campaign for the spring mission was carried out from the *CCGS Hudson,* with the 4 core transects being occupied. The CCGS Hudson was disabled in late summer through early fall with the result that our fall shelf survey was cancelled outright. However, the shelf portion of the Halifax line was sampled by Institut Maurice-Lamontage (IML) staff at the start of their ice-forecast mission in the Gulf of St. Lawrence. Sampling was performed on the Halifax Line in May 2010 during the Labrador Sea mission. The five new deep-water stations added to the Halifax line were successfully sampled at that time, but two shelf stations were not occupied.

The standard sampling suite when occupying section stations consisted of:

- CTD (SBE911 OSD Rosette) profile including electronic sensing of pressure, temperature, conductivity, dissolved oxygen, fluorescence, PAR, and pH.
- Niskin water bottle samples at standard depths for nutrients, calibration salinity, calibration oxygen, POC (Particulate Organic Carbon), flow cytometry, and plant pigment analyses (chlorophyll, HPLC [High Pressure Liquid Chromatography], absorbance),
- Niskin water bottle sample for phytoplankton enumeration, and
- Vertical ring net tows (202 and 76 µm mesh net) for zooplankton biomass (wet weight) and enumeration.

Trawl (groundfish) surveys. There are 4 primary trawl surveys in which AZMP-Maritimes/Gulf participates: the late winter (February) Georges Bank survey, the spring (March) eastern Scotian Shelf survey, the summer (July) Scotian Shelf/eastern Gulf of Maine survey, and the fall (September) southern Gulf of St. Lawrence survey (Figure 3). These surveys were all carried out in 2009 and 2010 by DFO's Population Ecology Division (PED) with AZMP participation. In 2009, there was an attempt to add a late winter (March) survey for the western Scotian Shelf (4X NAFO area) similar in scope to the start of the summer groundfish survey. Extreme weather and especially, vessel problems with *CCGS Needler* resulted in cancellation of that mission in both 2009 and 2010.

The standard sampling suite when occupying trawl survey stations consisted of:

- CTD (SBE25) profile including electronic sensing of pressure, temperature, conductivity, dissolved oxygen, fluorescence, and PAR,
- Niskin water bottle samples at surface (5 m) and near bottom depths (as a minimum, but 25 m and 50 m samples taken when possible) for nutrients, calibration salinity, calibration oxygen, and chlorophyll analyses,
- Niskin water bottle samples for phytoplankton enumeration taken at fixed station sites only,
- Vertical ring net tows (202 µm mesh net) for zooplankton biomass (wet weight) and enumeration at a subset of stations (see Figure 3), and
- Sea surface temperature recorder, trawl mounted depth/temperature recorders.

Deployment

CTD. The CTD is attached to the end of a hydrographic wire (or conducting cable for the rosette system) and lowered at ~0.3 m/sec for the portable SBE25 (~0.83 m/sec for the higher resolution SBE911 ship's rosette) to within 2 m of the bottom when possible.

Standard depths for water samples:

- Fixed-stations:
  1. Halifax-2: 1, 5, 10, 20, 30, 40, 50, 75, 100, 140 m.
  2. Shediac: 1, 5, 10, 20, 30, 40, 50, 60, 70, 80 m.
  3. Prince-5: 1, 10, 25, 50, 95 m.
- Seasonal sections – near-surface: 10, 20, 30, 40, 50, 60, 80, 100, 250, 500, 1000, 1500, 2000 m (depth dependent).
- Trawl surveys: 5, 25, 50 m, near bottom (when possible).

Net tows. Ring nets of a standard 202u mesh are towed vertically from near bottom to surface at ~1 m/sec. In deep offshore waters, maximum tow depth is 1000 m. The net is hosed carefully and sample collected from the cod-end, then preserved in buffered formalin.

Secchi depth. The Secchi disc is lowered slowly and the depth where it can no longer be visually detected is recorded.

Mixed-layer and Stratification Index

Two simple indices of the physical structure (vertical) of the water-column were computed for comparison with optical properties; mixed-layer and stratification.

1. The mixed layer depth was determined from the observations of the minimum depth where the density gradient ($gradient_z$(sigma-t)) was equal to or exceeded 0.01 (kg m^{-4}).

2. The stratification index ($Strat_{ind}$) was calculated as:

$$Strat_{ind} = (sig\text{-}t_{50} - sig\text{-}t_{zmin})/(50 - z_{min})$$

where $sig\text{-}t_{50}$ and $sig\text{-}t_{zmin}$ are interpolated values of sigma-t for the depths of 50 m and z_{min} (the minimum depth of reliable CTD data); typically z_{min} is around 5 m and always less than 9 m.

Optical Properties

Optical properties of the seawater (attenuation coefficient, photic depth) were derived from one or more of, (a) in-water light extinction measurements using a CTD-rosette mounted PAR meter, (b) Secchi depth, and (c) chlorophyll biomass profile, according to the following procedures:

1. The downward vertical attenuation coefficient for PAR ($K_{d\text{-}PAR}$) was estimated from the linear regression of $\ln(E_d(z))$ versus depth z (where $E_d(z)$ is the value of downward irradiance at z m) in the depth interval from minimum depth to 50 m (minimum depth is typically around 2 m and is always less than 6 m).

2. The value of K_d from Secchi disc observations was found using:

$$K_{d\_secchi} = 1.44/Z_{sd}\ (m^{-1})$$

where Z_{sd} = depth in m at which the Secchi disc disappears from view. The estimate of euphotic depth was made using the following expression:

$$Z_{eu}\ (m) = 4.6 / K_d$$

Reference values were calculated from all estimates of $K_{d\text{-}PAR}$ and K_{d_secchi}.

3. The value of Kd from chlorophyll biomass profile observations was calculated as:

$$K_{d\_chla} = 0.027 + 0.015 + 0.04{*}B_{exp}\ (m^{-1}) \qquad \text{(Platt et al. 1988)}$$

where B_{exp} is the observed values of chlorophyll a concentration B(z) (in mg m^{-3}) for depth interval from zero to z_e, the depth where the downwelling irradiance is 36.79% (e^{-1}) of the surface value. Chlorophyll observations were linearly interpolated each 0.25 m to calculate B_{exp}; K_{d_chla} was calculated over the interval 0 to z_e from:

$$E_d(0){*}\exp(-K_{d\_chla}{*}z_e) = (1/e){*}\ E_d(0), \text{ i.e.}$$

$$K_{d\_chla}{*}z_e = \Sigma\,(0.027 + 0.015 + 0.04 * B(z_i)){*}dz_i = 1$$

Integrated chlorophyll for the depth intervals 0–100 m (0–95 m for the Prince-5 fixed station) were calculated as the sum of products $Chl_i * dd_i$, where Chl_i is chlorophyll concentration measured for the depth z_i and dd_i is the depth interval around z_i: $dd_i = 0.5{*}(z_{i+1} - z_{i-1})$.

Satellite Remote-sensing of Ocean Colour

Phytoplankton biomass was also estimated from ocean colour data collected by the Sea-viewing Wide Field-of-view (SeaWiFS) satellite sensor launched by NASA (National Aeronautics and Space Administration) in late summer 1997 (http://seawifs.gsfc.nasa.gov/SEAWIFS.html), and the Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor (http://modis.gsfc.nasa.gov/). The MODIS data stream began in July 2002. Satellite data do not provide information on the vertical structure of phytoplankton in the water column, but do provide synoptic information on their geographical distribution in surface waters at the large scale. Twice monthly composite images (based on MODIS 1.5 km spatial resolution data) of surface chlorophyll for the entire Northwest Atlantic (39-62.5 N Lat., 42-71 W Lon.) are routinely produced and posted (http://www.mar.dfo-mpo.gc.ca/science/ocean/ias/seawifs/seawifs 3.html). Basic statistics (mean, range, standard deviation, etc.) are extracted from weekly composites for

selected sub-regions (Figure 4), for the fixed stations and for the seasonal sections. Operational problems with the SeaWiFS sensor data acquisition and navigation systems starting in 2007 resulted in significant gaps in the data products, thus, we have reverted to MODIS products only, starting with this report.

Starting in 2007, oceanographic conditions at the Shediac fixed station and conditions observed during the September southern Gulf of St. Lawrence trawl survey have been reported by the Quebec Region in order to better consolidate regional (i.e. entire Gulf of St. Lawrence) observations and interpretation.

Continuous Plankton Recorder

The Continuous Plankton Recorder (CPR) is an instrument that collects phytoplankton and zooplankton at a depth of ~7 m on a long continuous ribbon of silk (~260 μm mesh) while towed from commercial ships (Figure 5). The position on the silk corresponds to location of the different sampling stations. Historical CPR data are analysed to detect differences in the indices of phytoplankton (colour and relative numerical abundance) and zooplankton relative abundance for different years in the northwest Atlantic. The indices are measures of biomass or numbers of plankton collected in CPR samples and represent relative changes in concentrations from year to year (Richardson et al. 2006). The sampling methods from the first surveys in the northwest Atlantic (1961) to the present are exactly the same so that valid comparisons can be made between years.

Continuous Plankton Recorder (CPR) data up to 2009 were made available in February 2011. Since 2006 CPR sampling has not been optimal. In 2007 there was sampling only during the first half of the year, while in 2008 samples were collected only during the last half of the year. This gap was caused by a change in owners of the shipping company that runs the CPR lines in the NW Atlantic. In 2009, CPRs were towed during most months of the year, but between May and August the shipping company changed the route so as to go through the Strait of Belle Isle and into the Gulf of St Lawrence, rather than taking its usual route across the Newfoundland Shelf to St John's and on to Halifax via the South Newfoundland and Eastern Scotian shelves. CPRs were towed between Halifax and the Gulf of Maine during these summer months on a different vessel.

RESULTS

Mixing and Optical Properties

Mixing and optical properties of the upper water column varied by season and location at the Maritimes fixed stations (Figures 6 and 7). Seasonal development of the mixed-layer and upper water-column stratification were most evident at the Halifax-2 station (Figure 6); shallow mixed layers (<20 m) and maximum stratification (>0.09 kg m^{-4}) were evident in late summer and early fall months (August-October). Mixed-layer development at Halifax-2 in 2009 was consistent with the long-term average conditions. Mixed layers in late winter (March-April) were on occasion deeper (>80 m) than normal in both years. The development of stratification at Halifax-2 in 2009 and 2010, on the other hand, was consistent with the long-term average. In marked contrast to the Halifax-2 station, stratification was extremely low (<0.01 kg m^{-4}) at the Prince-5 station throughout the year, due principally to strong tidal mixing; this is a recurring feature of that station. Mixed-layer depths (MLDs) are highly variable and are difficult to determine at this station due to the very small vertical density differences (see Methods Section); MLDs normally

range from ~30-40 m in spring and early summer to almost full depth (90 m) in winter. In 2009 and 2010, mixed layer depths were similar to seasonal patterns seen previously.

Euphotic zone depth estimates derived from Secchi Disc readings and direct downwelling irradiance (PAR) measurements were generally comparable; PAR estimates were slightly shallower but not statistically different (Figure 7). Maximum vertical light attenuation (and shallowest euphotic zone depths) normally coincides with the spring bloom and euphotic depths are generally deepest during the decline of the bloom; this was evident at Halifax-2. Overall, euphotic depths in 2009 and 2010 were comparable in seasonal variability and magnitude at Halifax-2 and similar to the long-term average. At the Prince-5 station, in contrast, euphotic depths in 2009 and 2010 were considerably shallower (~20 m) than at Halifax-2, remarkably constant through the year but consistent with the long-term average at that station.

Nutrients

Fixed stations. Distributions of the primary dissolved inorganic nutrients (nitrate, silicate, phosphate) included in the observational program of AZMP strongly co-vary in space and time (Petrie et al. 1999). For that reason and because the availability of nitrogen is most often associated with phytoplankton growth limitation in our coastal waters (DFO 2000), emphasis in this report will be placed on variability in nitrate concentrations and inventories.

A clear spring/early summer biologically-mediated reduction in near surface nitrate concentrations was seen at both Maritimes fixed stations in 2009 and 2010 (Figure 8). Low surface values persisted throughout the summer/fall at Halifax-2, and concentrations did not increase at the surface again until late fall. The zone of nitrate depletion (i.e. defined as depths where concentrations were $\leq$1 mmol m^{-3}) in summer 2009 at Halifax-2 (38 m) was somewhat deeper than the long-term average (34 m); the depletion depth was slightly shallower than normal in 2010 (32 m). The seasonal evolution of the vertical nitrate structure at Halifax-2 in 2009 and 2010 was similar to that observed in previous years. Near surface nitrate concentrations at Prince-5 in 2009 and 2010 were never reduced below 2 mmol m^{-3}. The period of most rapid biological draw-down at Prince-5 in 2009 and 2010 (May) was comparable to the long-term conditions.

Strong seasonal variability in nitrate inventories of the upper 50 m (depth zone over which nutrient dynamics are strongly influenced by biological processes) is evident at both of the Maritimes fixed stations (Figures 9a, b). Seasonal patterns of variability and magnitude of nitrate at Halifax-2 in 2009 and 2010 were generally similar to that observed in previous years although winter inventories (0-50 m) were slightly lower than the norm in 2010. Winter inventories were 210-280 mmol m^{-2} and summer inventories were 50-60 mmol m^{-2}. Annual anomalies were close to the long-term average. Winter nitrate inventories in the upper 50 m at Prince-5 in 2009 were higher (530 mmol m^{-2}) than normal (460 mmol m^{-2}) in 2010. Summer inventories at Prince-5 were also higher (230 mmol m^{-2}) than the long-term average (200 mmol m^{-2}) but lower than the norm in 2010 (140 mmol m^{-2}). Annual anomalies indicated higher than normal inventories in 2009 and average inventories in 2010. Winter nitrate inventories in deep waters (>50 m) at Halifax-2 in 2009 were slightly higher (740 mmol m^{-2}) in 2009 and lower (660 mmol m^{-2}) in 2010 than long-term average (720 mmol m^{-2}). Annual anomalies indicated average conditions in 2009 but lower than normal inventories in 2010. At Prince-5, winter deep inventories were significantly higher in 2009 (480 mmol m^{-2}) and 2010 (520 mmol m^{-2}) than normal (~420 mmol m^{-2}). Summer deep inventories were also higher in 2009 (320 mmol m^{-2}) but lower in 2010 (220 mmol m^{-2}) than the norm (260 mmol m^{-2}). Annual anomalies indicated higher than normal inventories in 2009 and below normal inventories in 2010. Because of the relatively strong inter-annual

variability in nutrient concentrations at both fixed stations, it is difficult to discern a clear long-term trend in shallow and deep water nitrate inventories from the annual anomaly plots.

Shelf sections. Vertical distributions of nitrate in spring were generally similar along the Scotian Shelf sections in 2009 and 2010, i.e. concentrations were low (<2 mmol m^{-3}) in near surface waters (<50 m), as a result of phytoplankton consumption, and increased with depth (Figure 10a, b). Deep-water (>50 m) concentrations were highest in basins (>20 mmol m^{-3}) and in slope waters off the shelf edge. As in previous years, nitrate levels in surface waters were already reduced at the time of the spring survey in April (1 mmol m^{-3} depth horizon: ~20-50 m). Likewise, surface nitrate concentrations were still low during the fall survey in October-November (1 mmol m^{-3} depth horizon: ~20-50 m), with little evidence of seasonal mixing of nutrients from depth into surface waters (not shown). Vertical nitrate structure in spring along the Cabot Strait and Louisbourg sections was similar in 2009 and 2010 but deep water concentrations on the Halifax and Browns Bank sections, particularly in basins and off-shelf areas, were notably lower in 2010 (Figure 10b) than in 2009 (Figure 10a). Nitrate inventories in the upper 50 m were slightly lower than normal along the Cabot Strait section in 2009 and lower along the Halifax section in spring, 2010 (Figure 11a, b; Table 2). Deep-water (>50 m) inventories along the Halifax section were higher than normal (620-710 mmol m^{-2}) in spring and fall in 2009 (730-850 mmol m^{-2}) and higher in spring in 2010 (750 mmol m^{-2}). Deep inventories were also higher than normal in spring along the Cabot Strait section in 2009 (860 versus 720 mmol m^{-2}) but lower than normal in 2010 (580 mmol m^{-2}). Inter-annual variability in surface nitrate inventories along all sections, some of which could be attributed to differences in annual sampling dates, preclude the detection of any obvious long-term trends (Figure 11a). Deep-water inventories, however, are currently near record high levels and have been increasing since 2005-2006, particularly on the western shelf (Halifax and Browns Bank sections) (Figure 11b).

Trawl (groundfish) surveys. Bottom water nitrate concentrations on the Scotian Shelf in July 2009 (Avg: 11.3 mmol m^{-3}) and 2010 (Avg: 10.9 mmol m^{-3}) were not significantly different from the long-term average, 11.3 mmol m^{-3} (Table 3). Concentrations increased with water depth with highest levels observed in the deep basins on the shelf (e.g. Emerald Basin) and in slope waters off the shelf edge, as have been seen in the past (Figure 12a,b). Bottom water oxygen saturation in 2009 and 2010 (Avg: 77% and 79% sat, respectively) was also comparable to the long-term average (79% sat, Table 3). However, the area of the bottom covered by waters with <60% saturation was less in 2009 (20,400 km^2) than in 2010 (25,600 km^2); similar differences between the two years in bottom area covered by high nitrate concentrations (>15 mmol m^{-3}) was also noted. As usual, lowest oxygen saturations were found in deep basins (e.g. Emerald Basin) and deep waters off the shelf edge where nutrients are highest. There was no discernable long-term trend in bottom water nitrate concentrations or in oxygen content on the Scotian Shelf over the AZMP time series.

Phytoplankton

Fixed stations. Distinctly different seasonal phytoplankton growth cycles are evident at the two Maritimes fixed stations (Figures 13 and 14). The magnitude of the spring bloom observed at Halifax-2 in 2009 (peak: 670 mg m^{-2}) was considerably larger than the small bloom seen in 2008 (270 mg m^{-2}) and higher than the long-term average (470 mg m^{-2}). Bloom duration in 2009 (73 days) was also longer than the norm (44 days). In 2010, in contrast, the magnitude of the Halifax-2 bloom was well below the average, i.e. 320 mg m^{-3} and its duration was the shortest on record (12 days) (Figure 15a). The anomalously short bloom duration in 2010, however, may have been a sampling artefact since independent data (satellite ocean colour) do not support the fixed station measurements. The timing of the bloom in 2010 was earlier (max on day 68)

than usual (day 97); this is also evident in the monthly anomaly plots, showing sharp positive followed by negative values before and after the normal bloom period (Figure 14). Besides changes in bloom dynamics, the "background" chlorophyll levels (outside the bloom period) have declined over the AZMP time-series, from ~35 mg m^{-2} in 1999 to ~24 mg m^{-2} in 2010 (Figure 15b). Concentrations declined most rapidly from 1999-2003 and have been relatively stable or increased slightly (23-28 mg m^{-2}) since then. No clear long-term trends were seen in the annual chlorophyll anomalies (Figure 14).

The evolution of the phytoplankton community composition at Halifax-2 in 2009 and 2010 was broadly similar to that seen previously, i.e. diatoms dominated in the winter/spring, i.e. >75% of the total count, and flagellates and dinoflagellates dominated (>60% of the total count) the rest of the year (Figure 16). In both years, however, the relative abundance of ciliates was higher than normal. Also of note is the total abundance of autotrophic microplankton (diatoms, dinoflagellates, flagellates) was substantially reduced in both years but particularly so in 2010 where total counts were ~13,000 cells mL^{-1} compared to the normal abundance of ~86,000 cells mL^{-1} (not shown). These unusually low counts could not be reconciled with background chlorophylls levels which were not reduced proportionally.

The phytoplankton growth cycle at Prince-5, in contrast to Halifax-2; is characterized by a primary burst of growth in early summer (usually June) with secondary peaks in late summer or fall (August-September) (Figures 13 and 14). The magnitude of the early bloom in 2009 (170 mg m^{-2}) was small compared with the average (400 mg m^{-2}) and its duration (65 days) was also close to the norm (70 days). The bloom in 2010 was also somewhat smaller than usual (330 mg m^{-2}) but it was later (day 165) than usual (day 127) and its duration was considerably longer than usual, i.e. 99 days. The peak of the bloom in 2010 also occurred considerably later (day 264) than usual (day 163) and high concentrations persisted longer than usual, i.e. the primary and secondary peaks apparently merged in this year. No long-term trends were evident in the annual chlorophyll anomalies (Figure 14).

As has been noted previously, the phytoplankton community at Prince-5 is comprised almost exclusively of diatoms (>90%) throughout the year (Figure 16). Similar to observations at Halifax-2, the relative abundance of ciliates has been higher than usual at Prince-5 in recent years, but particularly in 2010.

Shelf sections. Chlorophyll levels along all the shelf sections are always considerably higher in spring than in fall. Spring levels are also characterized by a high degree of spatial variability and such was the case in 2009 and 2010 (Figures 17a, b). Despite this variability, chlorophyll levels in 2010 were notably lower than in 2009 along all sections, most likely due to the fact that 2010 sampling did not occur until after the peak of the bloom whereas most of the bloom was captured in the 2009 sampling. High inter-annual variability has also characterized spring chlorophyll inventories (0-100 m) along all sections (Figure 18) and no clear long-term trends have been discernable. Fall inventories have been much less variable but still no long-term trends are apparent.

Trawl (groundfish) surveys. Near-surface chlorophyll levels during the 2009 and 2010 spring trawl surveys on the eastern Scotian Shelf showed a distributional pattern similar to that seen in previous years, i.e. high concentrations were seen off-shelf (>3 mg m^{-3}) and distributed generally west of Sable Island (not shown). Surface chlorophyll levels during the summer Scotian Shelf survey, on the other hand, were uniformly low (<1 mg m^{-3}) over the central and outer shelf. Elevated concentrations (>1 mg m^{-3}) were only observed near the coast off SW Nova Scotia and approaches to the Bay of Fundy, as observed in previous years (not shown). These areas are generally characterized by strong vertical mixing. Overall, average summer

surface chlorophyll concentrations on the Scotian Shelf in 2009 (0.55 mg m^{-3}) and 2010 (0.89 mg m^{-3}) were not statistically different from normal levels (0.67 mg m^{-3}) (Table 3). There is no discernable trend in shelf-wide chlorophyll concentrations over the AZMP time-series.

Satellite ocean colour. Satellite ocean colour (MODIS) data provide a valuable alternative means of assessing surface phytoplankton biomass (chlorophyll) at the AZMP fixed stations, along the seasonal sections, and at larger scales (Northwest Atlantic) and have the potential to provide temporal data and synoptic spatial coverage not possible from conventional sampling. For example, two-week composite images of the Maritimes Region in early March showed the characteristic off-shelf early development of the bloom near Sable Island in 2009 but, more importantly, showed that the spring bloom in 2010 was earlier than normal, intense and widespread, covering the entire shelf and Gulf of St. Lawrence (Figure 19). The unusually early bloom in 2010 can be clearly seen in chlorophyll anomaly plots starting in February and extending through April (Figure 20). Positive anomalies started in late February in the Gulf, on the eastern shelf and extended to the Grand Banks. They then spread north and south in early April and were followed by strong negative anomalies for the entire region in late April; in May, conditions were back to normal (not shown). Evaluation of seasonal variability of chlorophyll for the statistical sub-regions in the Maritimes (see Figure 4) showed that the spring bloom 2009 was similar in magnitude and timing to the long-term average but in 2010 the bloom was earlier and more intense than normal in most sub-regions (Figure 21). The 2010 satellite data for Halifax-2 (not shown) did not indicate an anomalously short duration bloom as suggested by the fixed station chlorophyll measurements; duration appeared to fall within the normal range of 30-50 days.

Zooplankton

Fixed stations. At Halifax-2, both zooplankton biomass and abundance of the biomass-dominant species *Calanus finmarchicus* exhibit annual cycles with a peak in April-May. In 2009 and 2010, zooplankton biomass was lower than average or average throughout most of the year, with the exception of a higher-than-average spring biomass peak in April of 2009 and higher-than-average biomass in winter 2009 (Figure 22). The timing of the spring biomass peak was similar to the climatological average in both years, but the 2009 and 2010 peaks appeared to be short, with lower-than-average biomass observed during the station occupation following the peak. The annual averaged abundance anomalies for zooplankton biomass were negative in both years at Halifax-2 (Figure 23a).

Throughout most of 2009, the abundance of *C. finmarchicus* was also lower than average at Halifax-2, and the annual average abundance anomaly was negative (Figures 22 and 23a), and the percentage of young copepodite stages observed during the spring was relatively low compared to other years (Figure 24). The zooplankton community at Halifax-2 is normally dominated by copepods throughout nearly all of the year. This was the case in 2009, when copepods dominated even during a transient summer pulse of bivalve larvae and cladocerans (Figure 25). Both total zooplankton and copepod abundance were relatively constant throughout 2009, with the highest abundance observed in the winter and fall, in contrast to the climatological annual cycle (Figures 25 and 26a). In 2009, the abundances of copepod nauplii, euphausiids, larvaceans, and *Calanus hyperboreus* were relatively low, while the warm water copepod *Paracalanus* spp. was more abundant than usual (Figure 27a).

In 2010, *C. finmarchicus* abundance was lower than average for much of the year at Halifax-2, except during strong peaks in April and June. During the spring, the *C. finmarchicus* population was dominated by early copepodite stages (Figure 24), and both strong positive and negative abundance anomalies were observed (Figure 23a). The annual averaged anomaly for *C.*

finmarchicus abundance was positive in 2010. The zooplankton community at Halifax-2 was dominated by copepods throughout 2010, even during a transient spring pulse of bivalve larvae (Figure 25). In contrast to 2009, annual abundance variability of both total zooplankton and of copepods was greater than average in 2010, with strong abundance peaks in April and June and relatively low abundance in early winter and in the fall (Figures 25 and 26a). The small copepod *Oithona similis* contributed to the strong abundance peaks in April and June, in addition to *C. finmarchicus* (Figure 26a), and low abundance of *O. similis* and the warm water copepod species *Paracalanus* spp. and *Centropages typicus* contributed to low copepod abundances in fall 2010 (Figures 26a and 27a).

At Prince-5, zooplankton biomass is normally low in the winter and early spring, and it reaches annual maximum values in July through October. Compared to Halifax-2, the abundance of *C. finmarchicus* at Prince-5 remains relatively low throughout the year, and the annual maximum in *C. finmarchicus* abundance occurs later, in the late spring or summer (June to September; Figure 22). In 2009, zooplankton biomass was unusually variable from month-to-month, but the annual averaged abundance anomaly was close to zero (Figures 22 and 23b). The timing of the summer abundance peak was similar to the climatological average (Figure 22). *Calanus finmarchicus* abundance was also variable at Prince-5 in 2009, with anomalously high values in February, June, and August corresponding with months of high zooplankton biomass, and lower-than-average abundance in other months (Figure 22). The zooplankton community at Prince-5 is normally dominated by copepods for much of the year at Prince-5, particularly in the fall and early winter, but transient pulses of other taxa, which vary in composition from year to year, are typical in the spring and summer. In 2009, there was a pulse of barnacle larvae (included in "Others" in Figure 25) in the spring and euphausiid eggs and nauplii and cladocerans in the summer (Figure 25). Several small copepods, including *C. typicus*, *O. similis*, *Acartia* spp., *Pseudocalanus* spp., and *Temora longicornis,* were relatively low in abundance in 2009, and total copepod abundance was particularly low in July (Figures 26b and 27b).

Throughout most of 2010, both zooplankton biomass and *C. finmarchicus* abundance were close to average or below average at Prince-5, and the annual averaged anomalies of both were slightly negative (Figure 22 and 23b). The summer zooplankton biomass peak appeared to start one month earlier than normal, in May, and the peak in *C. finmarchicus* abundance occurred in June of 2010 (Figure 22). In contrast to recent years, the early-fall *C. finmarchicus* population was dominated by early copepodite stages, mostly CII, with few later copepodite stages (Figure 24). In 2010 the largest pulses of non-copepods at Prince-5 were barnacle larvae ("Others") in the spring and bivalve larvae and cladocerans in the summer (Figure 25). The larvacean *Fritillaria* spp. also contributed to the community in the winter and spring ("Cnidaria + Appendicularia", Figure 25). In contrast to 2009, *Centropages* spp. juvenile stages, *O. similis*, *Acartia* spp., *Pseudocalanus* spp., *Temora longicornis,* and *Eurytemora longicornis* were abundant at Prince-5 in 2010 (Figures 26b and 27b).

Shelf sections. Several of the averaged zooplankton biomass estimates for shelf sections and trawl surveys in 1999 – 2008 are different than reported in previous research documents, due to errors identified in a comprehensive quality check conducted in 2010.

In 2009, springtime transect-averaged zooplankton biomass was similar to recent years on the Cabot Strait, Halifax, and Browns Bank Lines, but it was relatively high on the Louisbourg Line, comparable to the two highest years of the survey, 2001 and 2003 (Figure 28a). In fall 2009, transect-averaged zooplankton biomass was also similar to recent years on the Louisbourg, Halifax, and Browns Bank Lines, while it was relatively high on the Cabot Strait Line. Transect-averaged zooplankton biomass was also similar to recent years in springtime 2010. In fall 2010,

only the Halifax Line was sampled, and the lowest zooplankton biomass values of the time series were observed.

The abundance of *C. finmarchicus* was similar to recent years in springtime 2009 on the Cabot Strait and Louisbourg Lines, but it was relatively high on the central/western Scotian Shelf lines (Halifax and Browns Bank) (Figure 28b). *Calanus finmarchicus* abundance was similar to normal values in fall 2009, with the highest values in the Emerald Basin (Halifax Line) and in the western Cabot Strait. In springtime 2010, *C. finmarchicus* abundance was high on the Louisbourg, Halifax, and Cabot Strait Lines and low on the Browns Bank Line. In fall 2010, *C. finmarchicus* abundance was low on the Halifax Line, possibly due to bias introduced by the absence of sampling at the station in the Emerald Basin.

Trawl (groundfish) surveys. In both 2009 and 2010, zooplankton biomass was low on Georges Bank in February but high on the eastern Scotian Shelf in March (Figure 29a; but sampling was very limited on the eastern Scotian Shelf in 2009). Zooplankton biomass was low on the Scotian Shelf in July in both 2009 and 2010.

In 2009, average *C. finmarchicus* abundance was comparable to the lowest value on record in February on Georges Bank, but the highest on record on the Eastern Scotian Shelf in March (Figure 29b). The average *C. finmarchicus* abundance on the Scotian Shelf in July 2009 was the lowest on record. In 2010, average *C. finmarchicus* abundance was moderate on Georges Bank in February. It was the second highest on record in March 2010 on the Eastern Scotian Shelf, while it remained low in July on the Scotian Shelf.

Continuous Plankton Recorder

Phytoplankton abundances. On the western Scotian Shelf, wintertime (January, February and March) diatom abundances were much higher in the '90s and '00s than they were in the '60s and '70s (Figure 30). In 2009, diatoms abundances in January and February were low, similar to those of the '60s and '70s, but in March they were high, similar to those of the '90s and '00s. In April all decades had high diatom abundances, but in 2009 diatom levels were generally lower than in other decades (and the rest of the '00s) from May to October, rising to normal levels in November and December. Phytoplankton colour index[1] (PCI) values in 2009 were generally lower that '90s and '00s levels in January-April and October-November, but otherwise more-or-less normal. Dinoflagellate abundance in 2009 was very low in January and February and much higher than in previous decades in March. Values were much lower than in previous decades in October and November, but otherwise close to normal.

On the Newfoundland Shelf, all three phytoplankton abundance indices had similar monthly abundances in 2009 to those seen in previous decades, except that dinoflagellate abundance in April was much higher (Figure 30). There was, however, sampling only during 5 months in 2009.

Zooplankton abundances. On the western Scotian Shelf, the abundance of *Calanus* I-IV (composed almost entirely of *Calanus finmarchicus* young stages) in 2009 was similar to values in previous decades, and the same was true for *C. finmarchicus* V-VI, a group including the later stages of the same species (Figure 31). *Calanus glacialis* was nearly absent in 2009, which has never been the case in previous decades. *Calanus hyperboreus* was also nearly absent, similar to the conditions of the '60s and '70sand in contrast to the relatively high levels of the '90s and '00s. These reductions suggest that conditions in the source populations in the Gulf of

[1] The phytoplankton colour index is a semi-quantitative estimate of total phytoplankton abundance.

St. Lawrence may have been especially unfavourable for these arctic species in 2008 or early 2009.

On the Newfoundland Shelf, the abundances of young and late stage *C. finmarchicus* were generally not very different from values seen in previous decades, and the sampling was too sparse to judge whether annual average abundances were more similar to the relatively high values of the '60s and '70s or to the relatively low values of the '90s and '00s (Figure 31). *Calanus glacialis* and *C. hyperboreus* abundances, however, seemed to have decreased from the high values of the '90s and '00s to levels closer to those of the '60s and'70s.

For other zooplankton taxa, the decadal seasonal cycles are not well defined, so that the sparse data from the Newfoundland Shelf region cannot usefully be compared with data from previous decades. On the Western Scotian Shelf, the following changes were noted when comparing 2009 with previous decades:

- The abundance of small copepods (*Paracalanus/Pseudocalanus*) was relatively low in winter, but otherwise normal;
- The abundances of copepod nauplii and *Oithona* spp. were relatively low throughout the year;
- The abundance of euphausiids showed no obvious changes;
- The abundance of hyperiids was slightly elevated;
- The abundance of foraminifera was unchanged;
- The abundance of pteropods was slightly elevated.

Scorecard. Scorecards of key indices, based on normalized, seasonally-adjusted annual anomalies, were developed in recent years to present physical, chemical, and biological observations in a compact format. A standard set of indices representing nutrient availability, primary production, and abundance of dominant copepod species and groups (*C. finmarchicus*, *Pseudocalanus* spp., total copepods, and total non-copepods) in each year at the fixed stations and on transects are produced in each of the AZMP regions, including the Maritimes (Figure 32).

While variability among indices and years is high in the standard scorecard, there has been considerable coherence among variables, from nutrients to zooplankton (Figure 32). Overall, 2009 was a year in which nutrients were high, phytoplankton was close to normal and the bloom was early, and zooplankton abundance was in general low on the Scotian Shelf. However, the abundance of *C. finmarchicus* was spatially variable and was higher than normal on the western part of the Scotian Shelf and in the Bay of Fundy in 2009. In 2010, it was impossible to calculate indices on several of the sections, due to the cancellation of the fall survey. The available data indicate that nutrient availability was low, and bloom timing and duration were variable, but the magnitude of the bloom was low. Zooplankton abundance anomalies were low, except at Prince-5 where anomalies of all of the groups reported, except for *C. finmarchicus*, were high.

DISCUSSION

Sufficient data now exists from AZMP observations (12 years) to document recurring spatial and temporal patterns in optical, chemical, and biological properties of the Maritimes Region and form the basis for detecting and quantifying changes (trends) in regional oceanographic and ecosystem properties. Although many of the properties in the Maritimes Region in 2009 and 2010 were similar to observations from previous years, a number of differences were noteworthy.

Mixing and optics. Optical properties and their seasonal variability at both fixed stations in 2009 and 2010 fell within the range of conditions that have been seen in previous years. At Halifax-2, photic depths follow the seasonal chlorophyll cycle with minimum values (~40 m) at the peak of the bloom and maximum values (~60 m) immediately after the bloom decline. In most cases, mixing properties (stratification, MLD) at the fixed stations in 2009 and 2010 were similar to the long-term average. An early bloom was seen throughout the Maritimes Region in 2010. While the seasonal mixed layer was deeper than normal in early spring of 2010, transient shallow mixed layers, which were observed in 2010 but not in 2009 (not shown), may have contributed to development of the early phytoplankton bloom in 2010. The transient shallow mixed layers may have been driven by event-scale phenomena such as temporary surface heating or freshening during an unusually warm year (Petrie et al. 2011).

Nutrients. Winter maxima in surface nutrients and summer-time reduction in concentrations are common features in the Maritimes Region. For the most part, the seasonal cycles of nutrients, vertical structure, and regional variations were similar in 2009 and 2010 to previous years; there were some differences, however. Summer nutricline depths in 2009 were deeper than usual and winter surface nutrient inventories were slightly lower than the norm at Halifax-2. At Prince-5, nitrate inventories were generally higher than the long-term average, winter and summer, in 2009 and 2010.

As already mentioned, warm winter conditions at Halifax-2, reflected in shallow MLDs, could have contributed to the lower than normal winter surface nutrient inventories and to an earlier than normal spring bloom in 2010. Higher than normal nutrients at Prince-5, in contrast, could have contributed to the extended duration of the summer bloom at that station in 2010.

Near-surface nutrient inventories along the shelf sections were generally similar in 2009 and 2010, but they varied by both location and season making a clear pattern difficult to detect. There were clear differences, however, in deep-water inventories in spring, with concentrations in deep waters on the shelf (e.g. Emerald Basin) and off the edge of the shelf being significantly lower in 2010 than in 2009, particularly on the western shelf (Halifax and Browns Bank sections). This likely indicated the incursion of Labrador Slope Water (LSW). By summer, nutrients in deep waters on and off the shelf were higher in 2010 than in 2009 and oxygen levels were lower, indicating the possible influence of Warm Slope Water (WSW). Over the longer term, however, deep-water inventories in 2009 and 2010 are among the highest seen on the shelf since AZMP observations started in 1999. Townsend at al. (2010) extended the nutrient time-series back even further, to the 1960s, and concluded that nutrient concentrations have, in fact, been decreasing over time, due largely to the increasing influence of cold-fresh arctic water entering the Maritimes Region *via* the shelf slope and the Gulf of St Lawrence. Yeats et al. (2010) refined Townsend's explanation by suggesting that, in addition to increased influence of arctic water in our region, the nutrient and oxygen characteristics of arctic source water are also being modified by ice melt and biogeochemistry (e.g. denitrification, remineralization). These changes, in turn, are modifying nutrient and oxygen concentrations in transit south. In other words, the nutrient and oxygen trends we observe are a balance between advective and internal biogeochemical processes. There is considerable debate currently on the influence of large-scale atmospheric processes, such as the NAO, on the advective processes (i.e. LSL versus WSW) that influence the nutrient trends we observe. Record low NAO conditions were observed in 2010 and the obvious question is, "What influence did the NAO have on local physical, chemical and biological processes in the Maritimes Region?" It is tempting to link the contrasting nutrients conditions seen in 2009 and 2010 to the dramatic changes in atmospheric properties over that period, but further analysis is required and oceanographic-ecosystem impacts may not

be apparent in the short-term but may take months to years to manifest, on time-scales of major water-mass circulation and transit.

Phytoplankton. Despite the fact that phytoplankton variability (both temporal and spatial) is characteristically high in coastal and shelf waters, the development of pronounced spring/summer (and less conspicuous fall) phytoplankton blooms are evident from observations at the Maritimes fixed stations, seasonal sections, trawl surveys, CPR, and remote-sensing data. Recurring spatial patterns such as the off-shelf bloom that develops in spring, elevated chlorophyll concentrations in summer off southwest Nova Scotia, Georges Bank, the eastern Gulf of Maine/Bay of Fundy, and the elevated concentrations on the eastern Scotian Shelf in fall, are observed almost every year. There were, however, some features of the phytoplankton growth cycle in the Maritimes Region distinctive for 2009 and 2010, the most prominent of which was the earlier than usual shelf-wide spring bloom in 2010.

Spring bloom timing (initiation) is thought to be regulated principally by the phytoplankton's light environment that is, in turn, determined by incident irradiance and upper-ocean mixing. In 2009, the seasonal cycle of stratification, mixed layer development and progression of the spring bloom at the Halifax-2 fixed station followed a predictable pattern based on previous years' observations. In 2010, however, the spring bloom occurred much earlier than usual. An early bloom was also observed throughout the Scotian Shelf and on Georges Bank, in the Gulf of Saint Lawrence, on the Grand Banks and in the Labrador Sea (Maillet et al. 2011). An unusually early spring bloom on the shelf was also observed the first year of AZMP, in 1999, and was linked to unusually warm oceanographic conditions in spring and changes in the growth cycle and recruitment of zooplankton, fish and invertebrates (Head 2005, Ouellet et al. 2003). Temperatures were also anomalously high throughout the zone in 2010 (Colbourne et al., 2011, Galbraith et al. 2011, Petrie et al. 2011). The short-lived, shallow MLDs observed in winter 2010 at Halifax-2, if related to warmer than normal conditions, may provide a mechanism contributing to the earlier than normal bloom; this hypothesis will require further investigation. It is also noteworthy that the abundances of young (<10 cm) haddock and cod collected on the July, 2010 groundfish survey were much higher than normal and similar in magnitude to abundances see in 1999 survey (A Cook, pers. Comm.). However, the timing of the spring peaks in zooplankton biomass and *C. finmarchicus* abundance were not earlier than usual at Halifax-2, although transient, higher than normal abundance peaks of *C. finmarchicus* were observed. At Prince-5, tidal mixing strongly influences the timing of the bloom which generally starts later in the year (May/June) than at Halifax-2 (March/April). Bloom timing at Prince-5 in 2010 was later than normal, but we do not have a clear explanation for the delay since light and mixing conditions were normal.

Bloom magnitude is thought to be regulated largely by nutrient supply, and bloom duration is regulated by both nutrient supply and secondarily by loss processes such as aggregation-sinking and grazing (principally by zooplankton). In north temperate waters, winter stores of nutrients in surface waters are considered the principal fuel for the spring phytoplankton bloom. In 2010, the magnitude of the spring bloom at Halifax-2 was slightly below normal but its duration was the shortest on record; only 12 days compared with a normal duration of 44 days (although this may be an artifact as discussed earlier). The 2010 drawdown of nitrate (winter-summer difference in surface inventories) was 160 mmol m^{-2}. This can be compared with the spring bloom peak of 292 mg CHL m^{-2}. Assuming 1 mmol of nitrate produces 1 mg CHL, winter nutrient reserves in 2010 could only support about half of the bloom; this could have contributed to the shorter bloom duration. However, in 2009 the 221 mmol m^{-2} drawdown of nitrate supported only about 1/3 of the bloom (636 mg CHL m^{-2}) and the duration in 2009 was longer than normal, i.e. 73 days versus 44 days. Clearly, there are other nutrient sources that must have fueled the bloom (see Harrison et al 2008) and additional factors that contributed to the

short bloom duration in 2010 if it is real. At Prince-5, the spring-summer bloom 2010 was sustained much longer than normal and this can most likely be linked to higher nutrient inventories.

Recurrent patterns in the seasonal succession of phytoplankton communities at both Maritimes fixed stations were evident in 2009 and 2010. At the Halifax-2 station, a clear transition from diatom-dominated communities in winter/spring to flagellate-dominated communities in summer/fall is evident, although a slight increase in the contribution of ciliates was evident in 2010. In contrast to the normal pattern, a drastic reduction (1/3-1/10 normal abundances) in total autotrophic (diatoms, flagellates, dinoflagellates) cell counts was observed in 2009 and 2010, much greater than corresponding chlorophyll reductions would suggest. The reason for this precipitous drop in microplankton abundance is unknown. At the Prince-5 station, diatoms dominate the microplankton community year-round, a pattern that was repeated in 2009 and 2010.

Zooplankton. Like phytoplankton, zooplankton biomass, abundance, and community composition in the Maritimes Region are characterized by high spatial and temporal variability. Clear seasonal variability patterns are evident at the fixed stations and also in the spring and fall AZMP transect data. At Halifax-2, zooplankton biomass and *Calanus finmarchicus* abundance both peak in April-May on average. Peak abundance and timing are more variable at Prince-5 than at Halifax-2, and zooplankton biomass and *C. finmarchicus* abundance peaks occur later in the season at Prince-5, on average between July and September. The differences in the zooplankton seasonal cycle at these stations may reflect the differences in the seasonal timing of phytoplankton blooms at the two stations.

In 2009, the most notable trends in the Scotian Shelf zooplankton at Halifax-2 were lower-than-average zooplankton biomass and *C. finmarchicus* abundance. Although zooplankton biomass and *C. finmarchicus* abundance on transects and trawl surveys were variable in 2009, the abundances of other copepods and non-copepods were also lower-than-normal across most of the Scotian Shelf. The timing of the zooplankton biomass and *C. finmarchicus* peaks at Halifax-2 were similar to normal, and their duration was short. These patterns do not reflect the higher-than-normal and longer-than-normal phytoplankton bloom that occurred at Halifax-2 in 2009. Zooplankton community indicators (warm/cold species, small/large species) were mixed at Halifax-2 in 2009, possibly reflecting advection and mixing of different communities at the station during the year.

At Prince-5, zooplankton biomass and *C. finmarchicus* abundance were unusually variable in 2009, and the abundance of small copepods was low. *C. finmarchicus* variability in 2009 likely reflects the strong influence of spatial gradients and patchiness of this species' distribution in the Prince-5 area, which may dominate short-term variability signals over *in-situ* production at this site. On the other hand, the low abundance of small copepods at Prince-5 in 2009 and high abundance in 2010 corresponds with interannual variability patterns in chlorophyll concentrations and may reflect a closer relationship between primary production and small copepod production at the annual scale in this region.

In 2010, the timing of the zooplankton biomass and *C. finmarchicus* peaks were normal at Halifax-2, despite the early phytoplankton peak, but the early peak could have contributed to the unusually high peaks in *C. finmarchicus* abundance in the spring, through enhanced survival. While zooplankton abundance was close to normal overall in 2010, positive anomalies for several zooplankton groups were more prevalent on the eastern Scotian Shelf, possibly reflecting enhanced production under the warmer temperatures in the eastern part of the region (Hebert et al. 2010).

2010 was a record low NAO year, and environmental conditions were warmer than usual throughout the Atlantic Zone in 2010, including on the Scotian Shelf. The Scotian Shelf is a spatial transition region in its environmental response to NAO variability, with warmer, saltier (colder, fresher) conditions on the eastern Scotian Shelf during periods of negative (positive) NAO and the opposite response on the central and western Scotian Shelf, including Emerald Basin (Petrie 2007). The environmental response to the NAO on the central and western Scotian Shelf may be driven by changes in transport of Labrador Slope Water and on-shelf transport of slope water (Petrie 2007). This advective mechanism suggests that the environmental response on the central and western Scotian Shelf lags NAO forcing by a year or more, and therefore the low NAO in 2010 may portend zooplankton community changes on the Scotian Shelf in 2011 or 2012.

Scorecard. The scorecard, based on normalized, seasonally-adjusted annual anomalies, provides a tool for visually integrating the suite of chemical and biological observations made in AZMP. The key variables selected for the chemical-biological observations across the Atlantic Zone include: (1) near surface (0-50 m) and deep (50-150 m) nitrate inventories, and (2) chlorophyll inventories (0-100 m), the magnitude, timing, and duration of the spring bloom, and zooplankton abundances (*C. finmarchicus, Pseudocalanus* spp., total copepods, total non-copepods) for the fixed stations and seasonal section surveys. By combining these indicators under the broad categories of nutrients, phytoplankton and zooplankton we are able to examine how these 'aggregate indices' relate to one another providing insight, for example, into "bottom-up" (nutrient-driven) versus "top-down" (grazing-driven) ecological controls.

Despite considerable variability among variables and years, several patterns have emerged from the Maritimes Region's scorecard (Figure 32). The first is that for years where there were overall high (or low) scores within an aggregate group (i.e. nutrients, phytoplankton, zooplankton) there was considerable coherence among the variables making up that aggregate (e.g. the positive nutrient anomalies and negative zooplankton anomalies in 2009). Secondly, dramatic shifts from positive to negative anomalies can be seen between adjacent years (e.g. the shift from positive to negative nutrient anomalies between 2009 and 2010). Thirdly, positive or negative anomalies within a variable or group of variables may persist for multiple years (e.g., the negative zooplankton anomalies between 2004 and 2007).

Overall, nutrient anomalies were at a record high in 2009 and shifted to a near record low in 2010. Unfortunately, the loss of the 2010 fall surveys along 3 of the 4 sections limited the data available for developing the indices. Considering the complete AZMP time-series, there have been about as many positive nutrient anomalies as negative ones, however, the strongest positive anomalies have occurred in recent years, with the exception of 2010. For phytoplankton as well, there have been about as many positive as negative anomalies but the strong positives were in the early AZMP years; more recently, the phytoplankton anomalies have been near zero, i.e. conditions have close to the long-term average. Zooplankton anomalies, both positive and negative, have been the most extreme of the three aggregate indices. Moreover, persistence of conditions, i.e. generally negative anomalies since 2004, have been the message for zooplankton in the Maritimes. Overall, covariance has been weak among the aggregate indices over the 12 years of AZMP observations, even when large swings in anomalies have been observed. Establishing a clear cause-effect relationship among nutrients, phytoplankton and zooplankton is still elusive.

SUMMARY

- Optical properties at the Maritimes fixed stations in 2009 and 2010 were comparable to conditions observed in previous years.
- Annual nutrient anomalies were at record high levels in 2009 and near record low levels in 2010 in Maritimes waters.
- The seasonal growth cycle of phytoplankton in 2009 was similar to conditions seen previously, but in 2010, the spring bloom started much earlier than usual and was similar to the conditions seen in 1999 when AZMP started. 2010 may be a strong year-class for both cod and haddock, as 1999, based on preliminary data analysis.
- Annual phytoplankton anomalies suggested conditions were near normal in 2009 and 2010 despite the early spring bloom in 2010.
- Overall annual zooplankton anomalies were lower than normal in 2009 and near normal in 2010.
- Zooplankton biomass seasonal peak timing was normal or near normal in both years.
- *Calanus finmarchicus* and total copepod abundance were below average at Halifax-2 during much of 2010, but it exhibited strong peaks in April and June 2010.
- Zooplankton biomass and abundance anomalies were spatially variable in 2010, with positive anomalies in the Cabot Strait and Eastern Scotian Shelf.
- The low NAO observed in 2010 may portend changes in the physical, chemical, and biological environment of the Scotian Shelf in 2011 – 2012.

ACKNOWLEDGEMENTS

The authors wish to thank the sea-going staff of the Ocean Research and Monitoring Section at the Bedford Institute of Oceanography (BIO) and staff at the St. Andrews Biological Station (SABS), and the officers and crew of the *CCGS Opilio, Hudson, Needler, Teleost* and *SAR* vessels for their able assistance in successfully completing the Maritimes/Gulf regions' 2009/10 field program. Jackie Spry (contractor – Sprytech Biological) provided expert identification and enumeration of zooplankton. Pierre Pepin and Michel Harvey provided helpful comments to improve the manuscript.

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Table 1a. Atlantic Zonal Monitoring Program (AZMP) sampling missions in the Maritimes/Gulf regions, 2009. SGSL = Southern Gulf of St. Lawrence.

Group	Location	Mission ID	Dates	# Hydro Stns	# Net Stns
Trawl Surveys	Georges Bank	NED2009-841	Feb 11 - 21	34	9
	Eastern Shelf	NED2009-002	Mar 23 – Apr 02	44	11
	Scotian Shelf	NED2009-027	Jul 01 – Aug 01	202	31
	SGSL	TEL2009-892	Sept 08 - Oct 01	158	16
Seasonal Sections	Scotian Shelf	HUD2009-005	Apr 11 – Apr 28	68	54
	Scotian Shelf	HUD2009-015	May 30 – 31	10	5
	Scotian Shelf	HUD2009-048	Sep 26– Oct 19	69	58
Fixed Stations	Shediac Valley	BCD2009-668	May 01 – Nov 30	7	7
	Halifax-2	BCD2009-666	Jan 01 – Dec 31	18 (7)[1]	18 (7)[1]
	Prince-5	BCD2009-669	Jan 01 – Dec 31	12	12
			Total:	611	210

[1]Total station occupations, including occupations during trawl surveys and seasonal sections (dedicated occupations with mission ID as listed at left)

Table 1b. Atlantic Zonal Monitoring Program (AZMP) sampling missions in the Maritimes/Gulf regions, 2010. SGSL = Southern Gulf of St. Lawrence.

Group	Location	Mission ID	Dates	# Hydro Stns	# Net Stns
Trawl Surveys	Georges Bank	NED2010-001	Feb 23 – Mar 09	35	8
	Eastern Shelf	NED2010-002	Mar 11 – 30	71	15
	Scotian Shelf	NED2010-027	Jul 06 – Aug 01	197	27
	SGSL	TEL2010-974	Sept 07 – 29	145	16
Seasonal Sections	Scotian Shelf	HUD2010-006	Apr 08 – 25	82	67
	Scotian Shelf	HUD2010-014	May 27 – 29	11	4
	Scotian Shelf	HUD2010-070[1]	Sep 07– 09	7	5
	Scotian Shelf/slope	HUD2010-049	Dec 16 - 20	10	4
Fixed Stations	Shediac Valley	BCD2010-668	Apr 01 – Nov 30	7	7
	Halifax-2	BCD2010-666	Jan 01 – Dec 31	18 (7)[2]	17 (7)[2]
	Prince-5	BCD2010-669	Jan 01 – Dec 31	12	12
			Total:	584	172

[1]IML Ice Forecast mission
[2]Total station occupations, including occupations during trawl surveys and seasonal sections (dedicated occupations with mission ID as listed at left)

Table 2. Chemical and biological properties of the 1999-2010 spring and fall Scotian Shelf sections. Statistics: Section means (average of all stations).

		Nitrate 0-50 m (mmol m^{-2})		CHL 0-100 m (mg m^{-2})		Zoopl Biomass (g wet wt m^{-2})		*C. finmarchicus* (Indx10^3 m^{-2})	
Section	Year	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Cabot	**1999**	133	140	423	47	23	40	17	38
	2000	92	31	549	38	29	33	5.3	29
	2001	31	120	137	35	90	86	6.2	28
	2002	-	238	-	69	-	-	-	-
	2003	-	76	-	38	-	85	-	39
	2004	98	81	326	26	79	271	8.3	34
	2005	137	84	157	34	67	47	18	22
	2006	48	144	260	11	55	87	9.8	30
	2007	140	110	291	37	37	64	11	41
	2008	140	122	168	41	60	52	12	24
	2009	100	107	320	38	62	88	7	25
	2010	59	119	150	36	-	-	-	-
Louisbourg	**1999**	99	91	177	53	17	8.8	68	10
	2000	94	24	378	38	13	8.4	23	3.0
	2001	29	72	152	39	95	34	13	13
	2002	-	37	-	41	-	43	-	27
	2003	81	71	710	39	90	16	15	6.7
	2004	48	77	405	29	47	30	10	23
	2005	48	79	397	30	56	17	21	9.8
	2006	62	94	151	28	42	16	29	8.4
	2007	72	92	597	24	29	12	12	15
	2008	115	41	195	39	45	31	14	38
	2009	82	56	162	47	80	25	20	12
	2010	72		107	-	-	-	-	-
Halifax	**1999**	144	93	53	36	17	10	65	8.0
	2000	90	22	165	45	18	14	47	8.9
	2001	29	99	126	31	90	25	52	8.2
	2002	-	38	-	25	-	21	-	7.0
	2003	51	53	313	35	80	29	54	8.9
	2004	44	56	77	34	53	71	33	8.8
	2005	63	60	354	30	41	28	56	11
	2006	80	64	39	6.7	50	30	27	15
	2007	52	63	720	35	29	25	19	10
	2008	119	100	267	44	41	37	25	15
	2009	110	27	254	39	59	41	5	14
	2010	94	60	89	58	-	-	-	-
Browns	**1999**	124	143	58	83	12	28	75	2.8
	2000	239	26	154	45	-	17	25	5.4
	2001	30	175	116	59	89	26	59	16
	2002	-	109	-	36	-	34	-	15
	2003	157	145	545	58	74	42	49	31
	2004	133	118	219	26	34	26	28	4.5
	2005	187	98	165	37	28	17	26	5.4
	2006	152	130	44	51	34	26	65	12
	2007	53	115	680	29	40	14	15	8.3
	2008	195	174	102	59	61	29	81	12
	2009	121	194	452	40	29	18	74	12
	2010	142		208	-	-	-	-	-

Table 3. Chemical and biological properties of the 1999-2010 summer Scotian Shelf ecosystem trawl (groundfish) survey. Statistics: means, ranges (in brackets), and number of observations. Numbers in brackets in the oxygen column represent the percent area of shelf covered by bottom waters with <60% oxygen saturation.

Year	Chlorophyll (mg m^{-3}) Surface (5 m)	Nitrate (mmol m^{-3}) Bottom	Oxygen (Percent saturation) Bottom	Zoopl Biomass (g wet wt m^{-2})	*C. finmarchicus* (Individuals m^{-2})
	0.93	**13.22**	**77 [7.3]**	**45.9**	**20,872**
1999	(0.10-7.07)	(2.12-24.06)	(41.9-106.7)	(0.2-228.2)	(91-143,060)
	137	163	197	32	33
	0.67	**12.87**	**87 [12.4]**	**34.0**	**37,625**
2000	(0.11-6.17)	(3.27-22.97)	(43-121)	(2.7-158.6)	(2.7-238.1)
	220	178	203	38	38
	0.78	**11.75**	**82 [9.9]**	**34.4**	**32,598**
2001	(0.03-4.08)	(1.72-21.76)	(40-107)	(1.2-144.8)	(43-185,472)
	206	155	206	38	37
	0.51	**10.96**	**74 [6.2]**	**27.0**	**25,906**
2002	(0.08-4.17)	(0.32-22.66)	(28-109)	(1.0-120.1)	(9-171,131)
	303	215	215	38	38
	0.72	**11.01**	**78 [9.7]**	**34.9**	**33,224**
2003	(0.03-6.65)	(0.14-23.27)	(34-109)	(1.07-252.5)	(1154-233,326)
	214	213	217	34	34
	0.56	**10.35**	**81 [12.8]**	**36.9**	**37,036**
2004	(0.12-5.25)	(0.14-24.28)	(36-110)	(2.51-182.2)	(151-219,398)
	185	193	191	38	38
	0.56	**10.98**	**78 [8.2]**	**19.5**	**19,181**
2005	(0.001-3.83)	(0.44-23.10)	(43-103)	(0.32-46.6)	(24-143,063)
	192	191	191	34	34
	0.69	**11.48**	**77 [5.2]**	**31.4**	**42,837**
2006	(0.05-4.74)	(0.01-22.82)	(41.62-110.58)	(1.81-135.76)	(431-109,560)
	201	207	207	41	41
	0.68	**9.56**	**77 [10.9]**	**26.9**	**29,703**
2007	(0.18-3.19)	(0.12-19.96)	(43.32-113.55)	(0.69-115.88)	(830-138,987)
	163	161	163	34	35
	0.64	**10.47**	**79 [7.8]**	**31.8**	**33,889**
2008	(0.06-4.43)	(0.72-22.79)	(41.2-112.4)	(1.56-121)	(144-114,991)
	165	167	165	31	31
	0.55	**11.32**	**77 [-]**	**23.9**	**16,198**
2009	(0.02-5.06)	(0.65-22.97)	(44.8-103.1)	(2.54-100)	(151-44971)
	200	188	188	31	31
	0.89	**10.86**	**79 [-]**	**17.5**	**20,470**
2010	(0.09-5.19)	(0.44-23.02)	(32.6-108.0)	(0.88-86.7)	(28-82,848)
	192	186	186	29	29

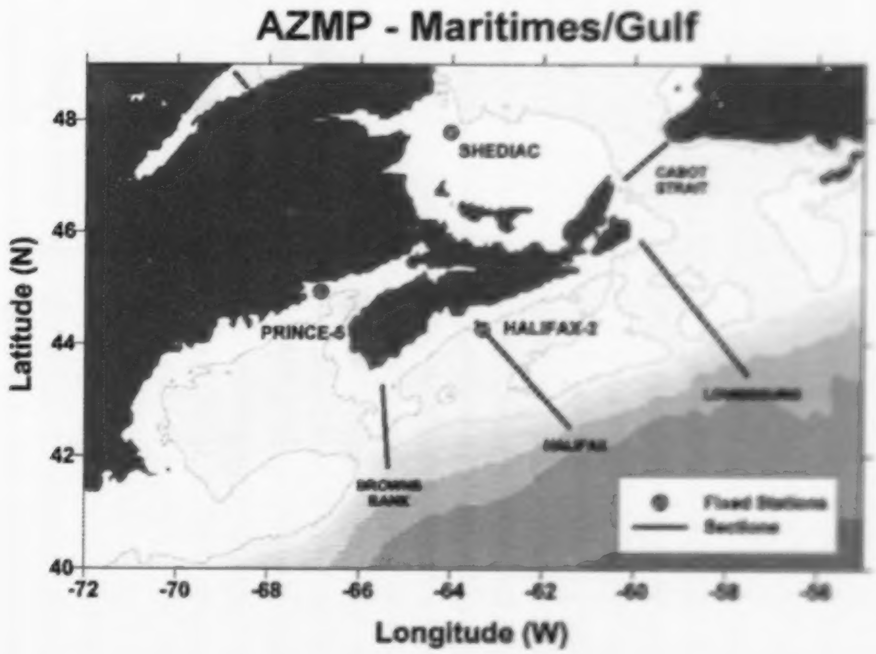


Figure 1. Primary sections and fixed stations sampled in the DFO Maritimes and Gulf regions.

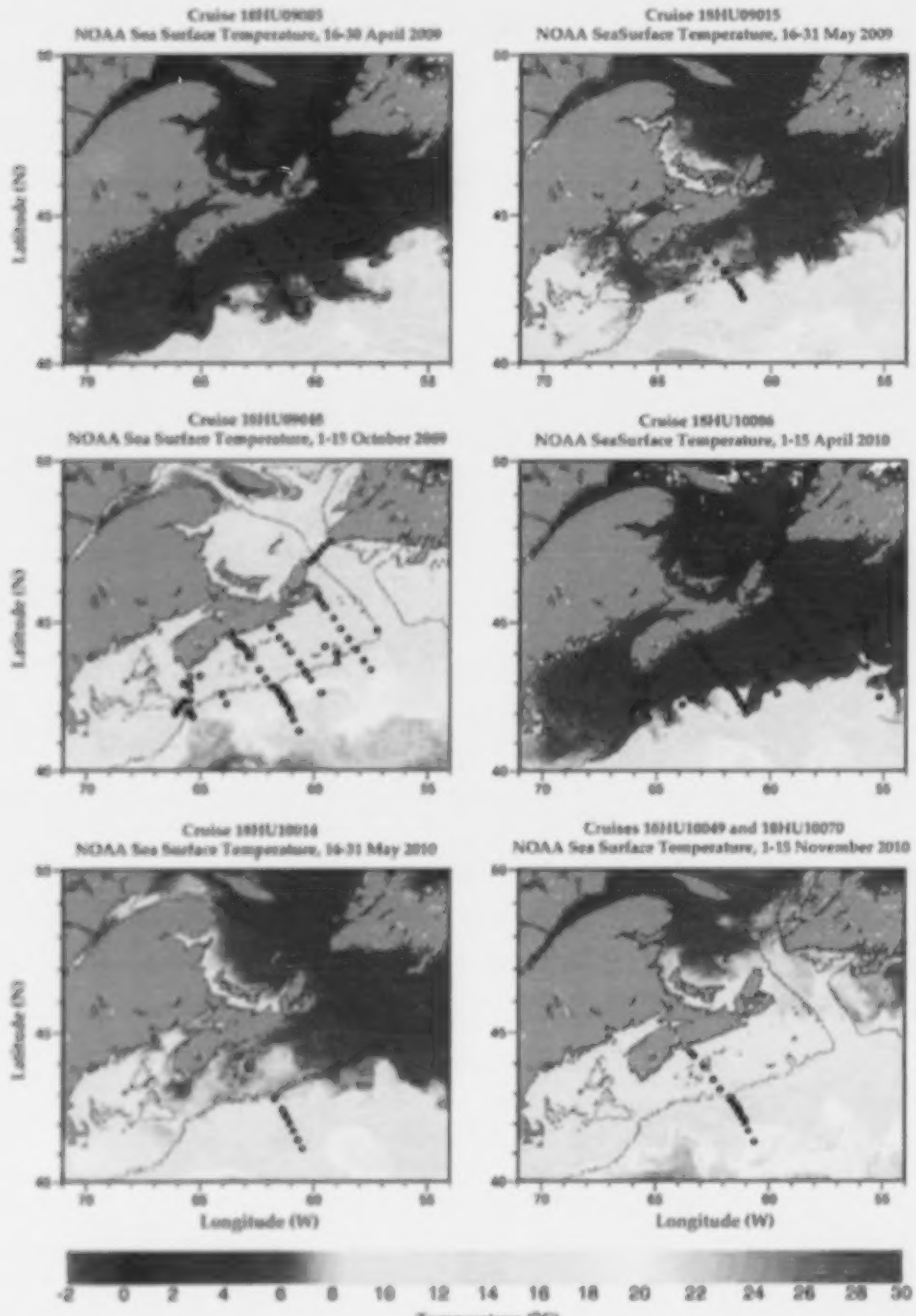


Figure 2. Stations sampled during the 2009 and 2010 spring, summer and fall section surveys. Station locations superimposed on twice-monthly sea surface temperature (SST) composite images.

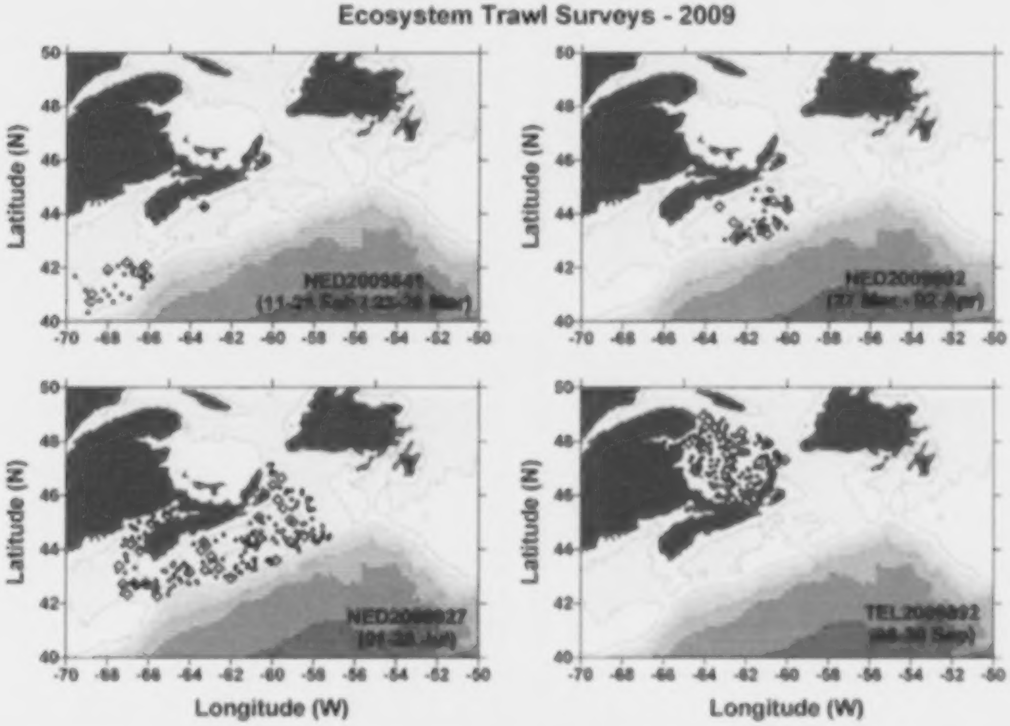


Figure 3a. Stations sampled during major Maritimes/Gulf trawl (groundfish) surveys in 2009. Black symbols are hydrographic stations; red symbols are stations where vertical nets hauls were taken in addition to hydrographic measurements.

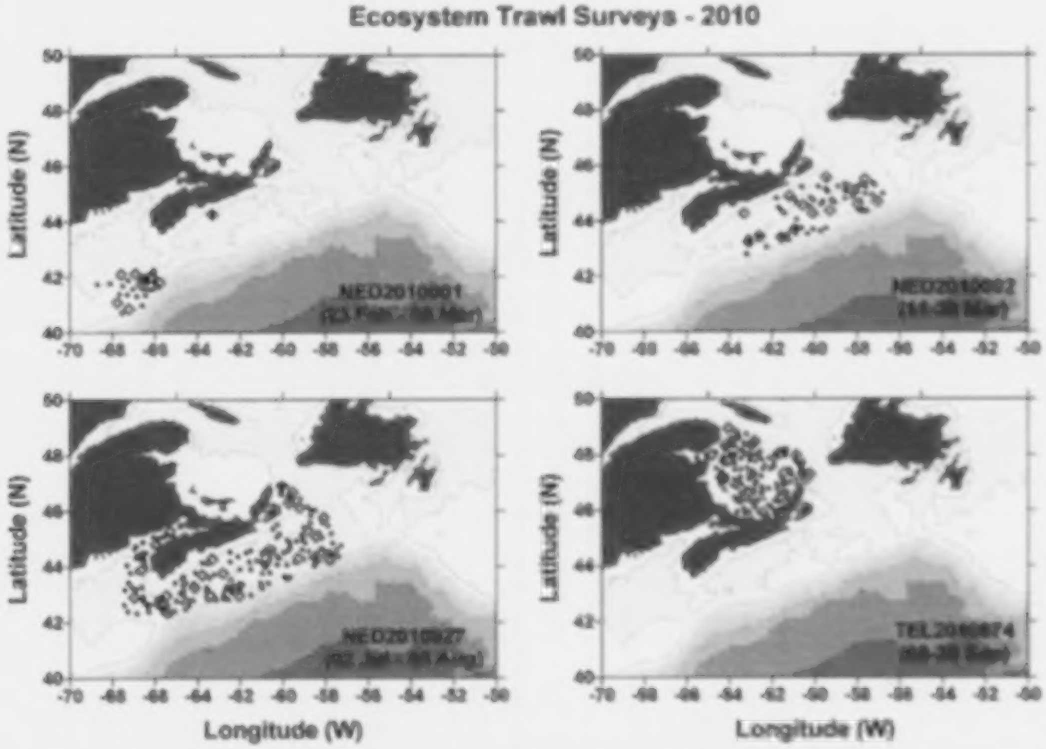


Figure 3b. Stations sampled during major Maritimes/Gulf trawl (groundfish) surveys in 2010. Black symbols are hydrographic stations; red symbols are stations where vertical nets hauls were taken in addition to hydrographic measurements.

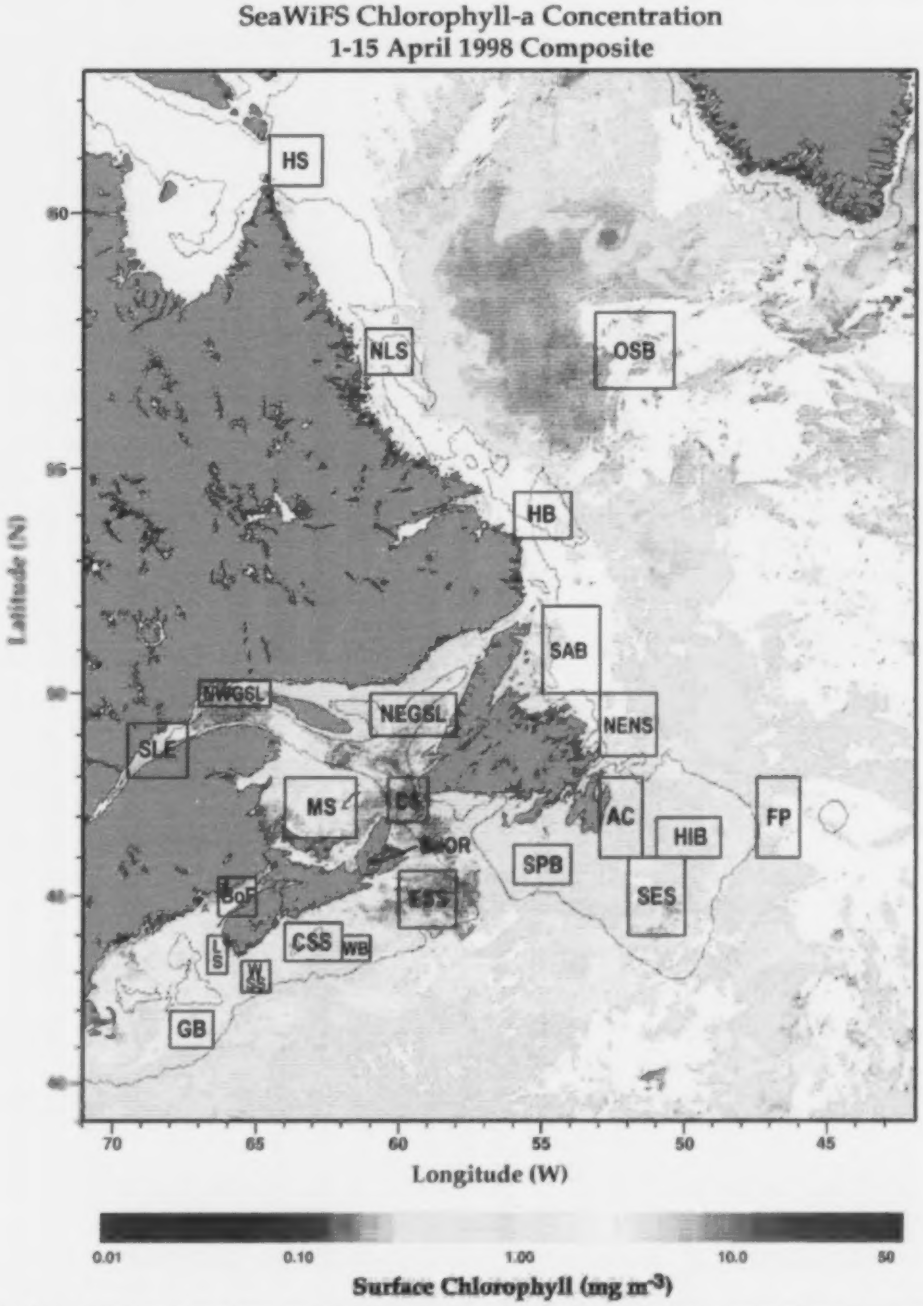


Figure 4. Statistical sub-regions in the Northwest Atlantic identified for spatial/temporal analysis of satellite ocean colour data. AC – Avalon Channel; BdOR – Bras d'Or; BoF – Bay of Fundy; CS – Cabot Strait; CSS – Central Scotian Shelf; ESS – Eastern Scotian Shelf; FP – Flemish Pass; GB – Georges Bank; HB – Hamilton Bank; HIB - Hibernia; HS – Hudson Strait; LS – Lurcher Shoal; MS – Magdalen Shallows; NEGSL – Northeast Gulf of St. Lawrence; NENS – Northeast Newfoundland Shelf; NLS – Northern Labrador Shelf; NWGSL – Northwest Gulf of St. Lawrence; OSB – Ocean Station Bravo; SAB – St. Anthony Basin; SES – Southeast Shoal; SLE – St. Lawrence Estuary; SPB – St. Pierre Bank; WB – Western Bank; WSS – Western Scotian Shelf;

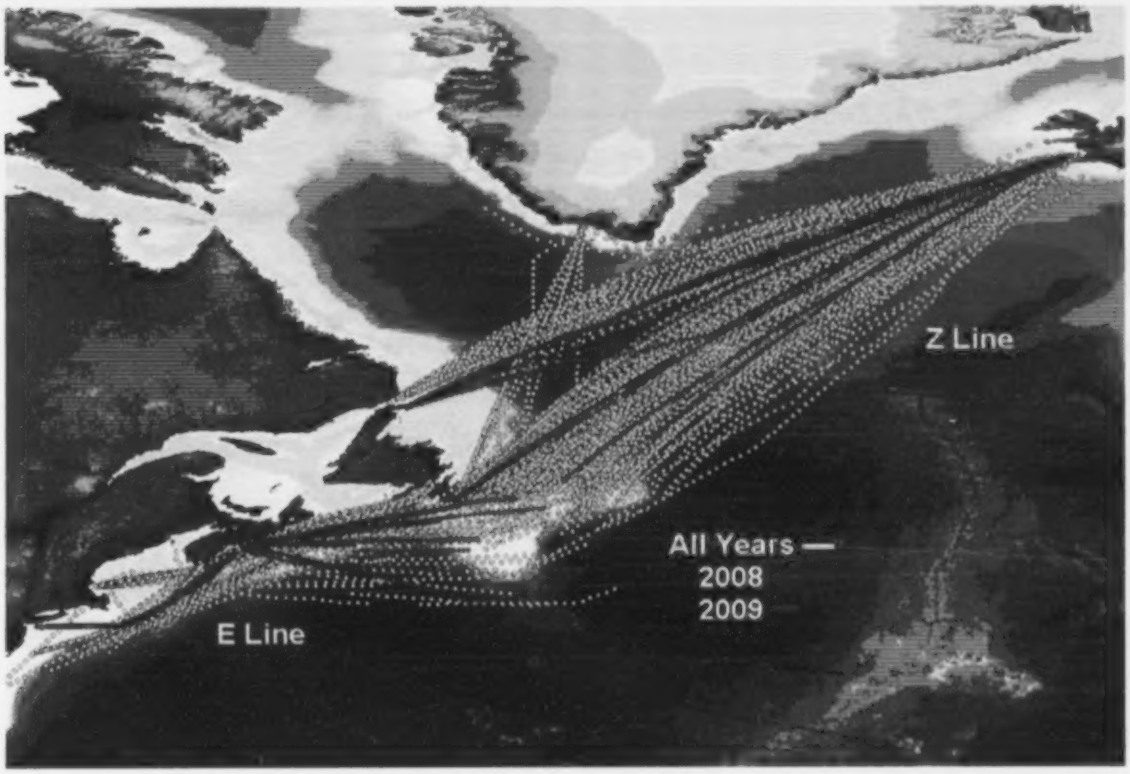


Figure 5. Continuous Plankton Recorder (CPR) lines and stations, 1961 to 2009 (2008 and 2009 highlighted).

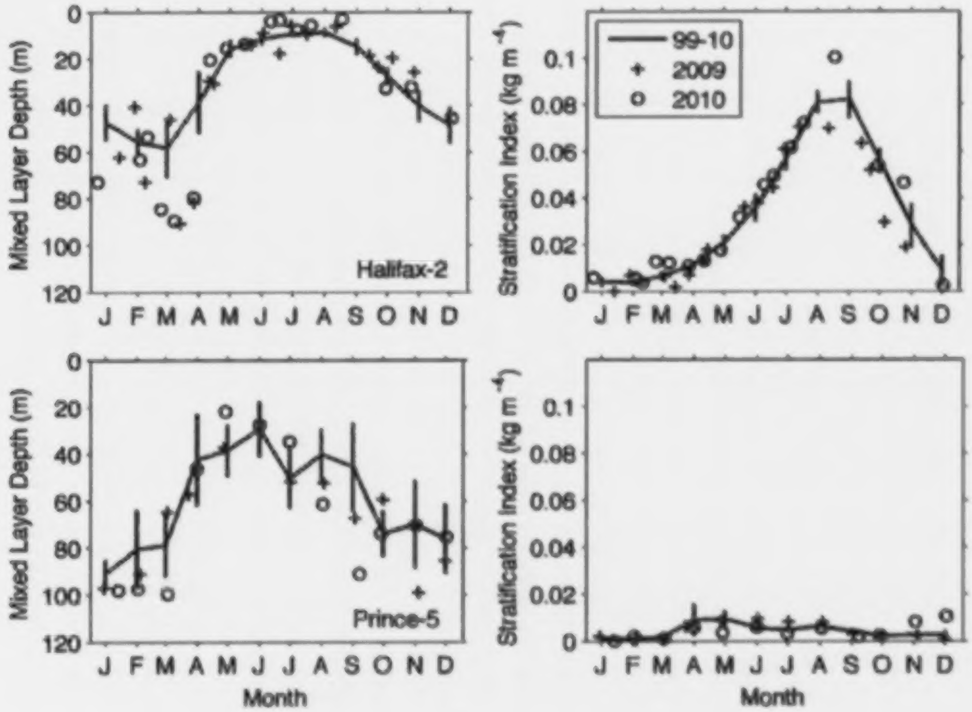


Figure 6. Mixing properties (mixed-layer depth, stratification index) at the Maritimes fixed stations. Year 2009 data (crosses) and 2010 data (circles) compared with mean conditions from 1999-2010 (solid line). Vertical lines are 95% confidence intervals of the observations.

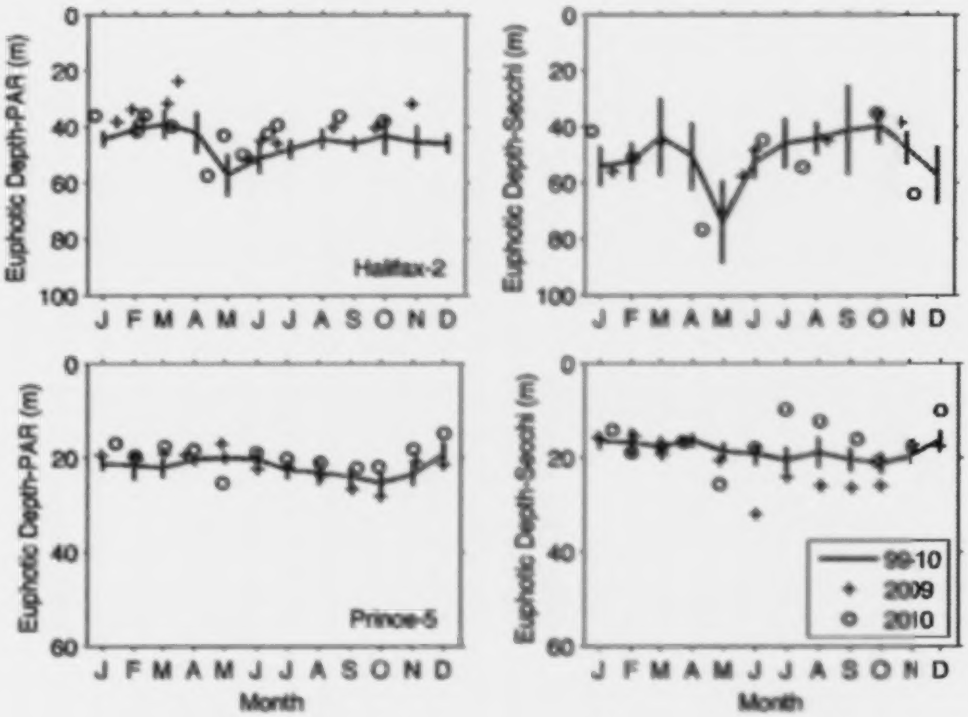


Figure 7. Optical properties (euphotic depth from PAR irradiance meter and Secchi disc) at the Maritimes fixed stations. Year 2009 data (crosses) and 2010 data (circles) compared with mean conditions from 1999-2010 (solid line). Vertical lines are 95% confidence intervals of the observations.

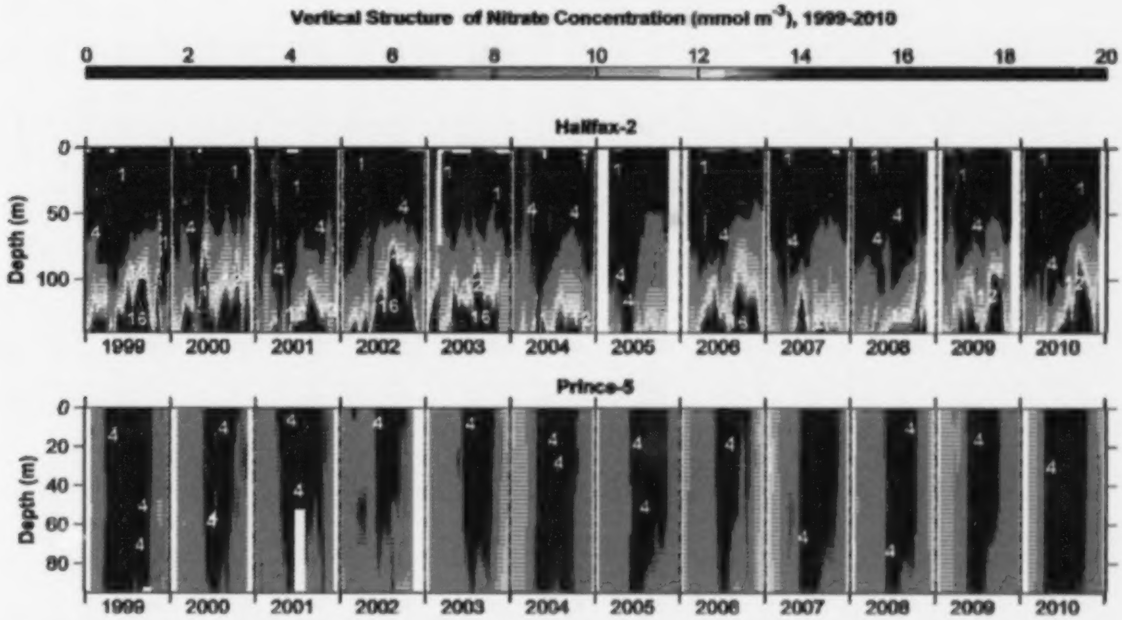


Figure 8. Time series of vertical nitrate structure at the Maritimes fixed stations, 1999-2010.

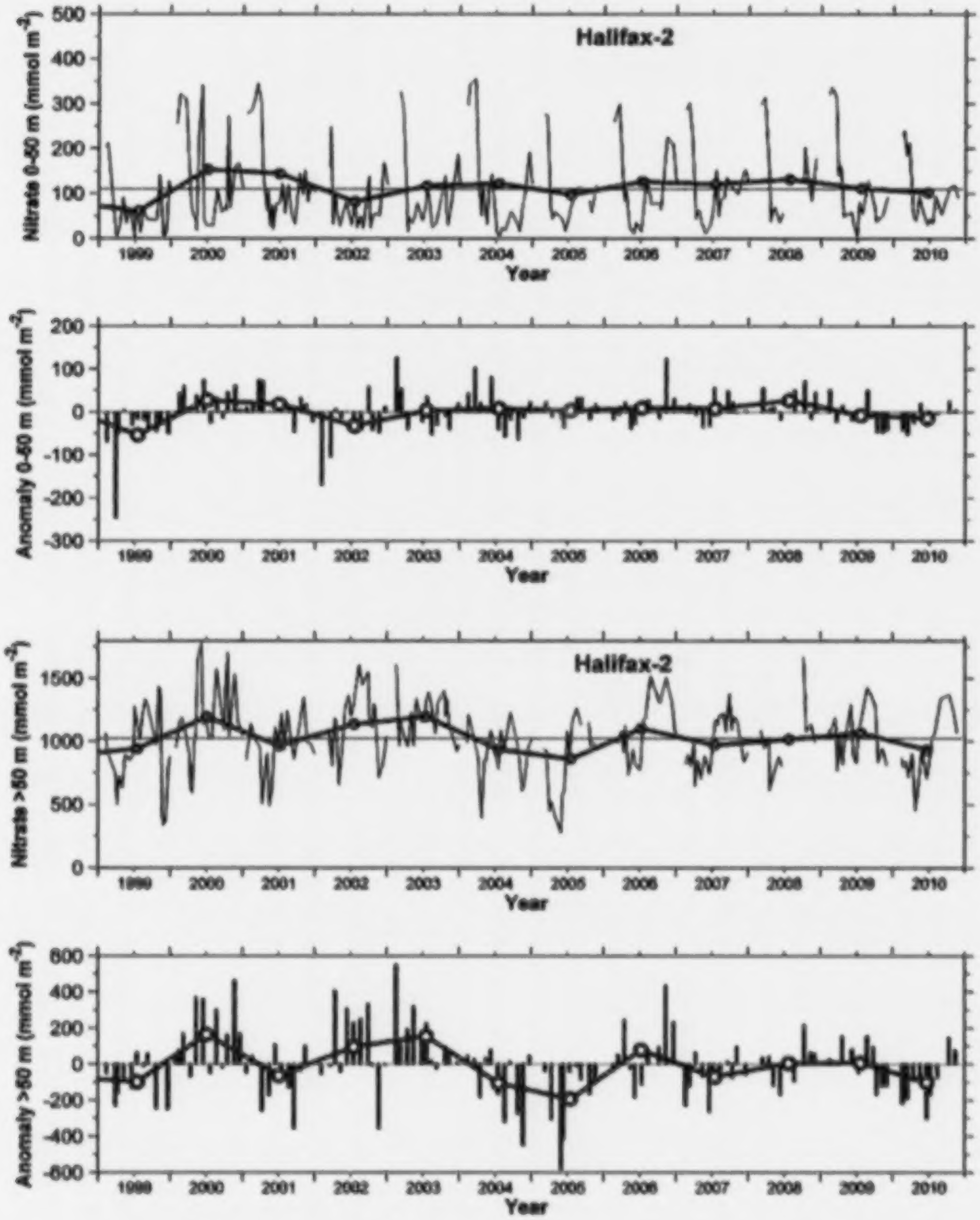


Figure 9a. Nitrate inventories at the Halifax-2 fixed station, 1999-2010. Top 2 panels: surface (0-50 m) time series with annual averages (solid line); monthly (vertical bars) and annual (solid line) anomalies. Bottom 2 panels: deep (>50 m) time series with annual averages (solid line); monthly (vertical bars) and annual (solid line) anomalies (reference period: 1999-2010). The overall mean is shown as a horizontal line in the first and third panels.

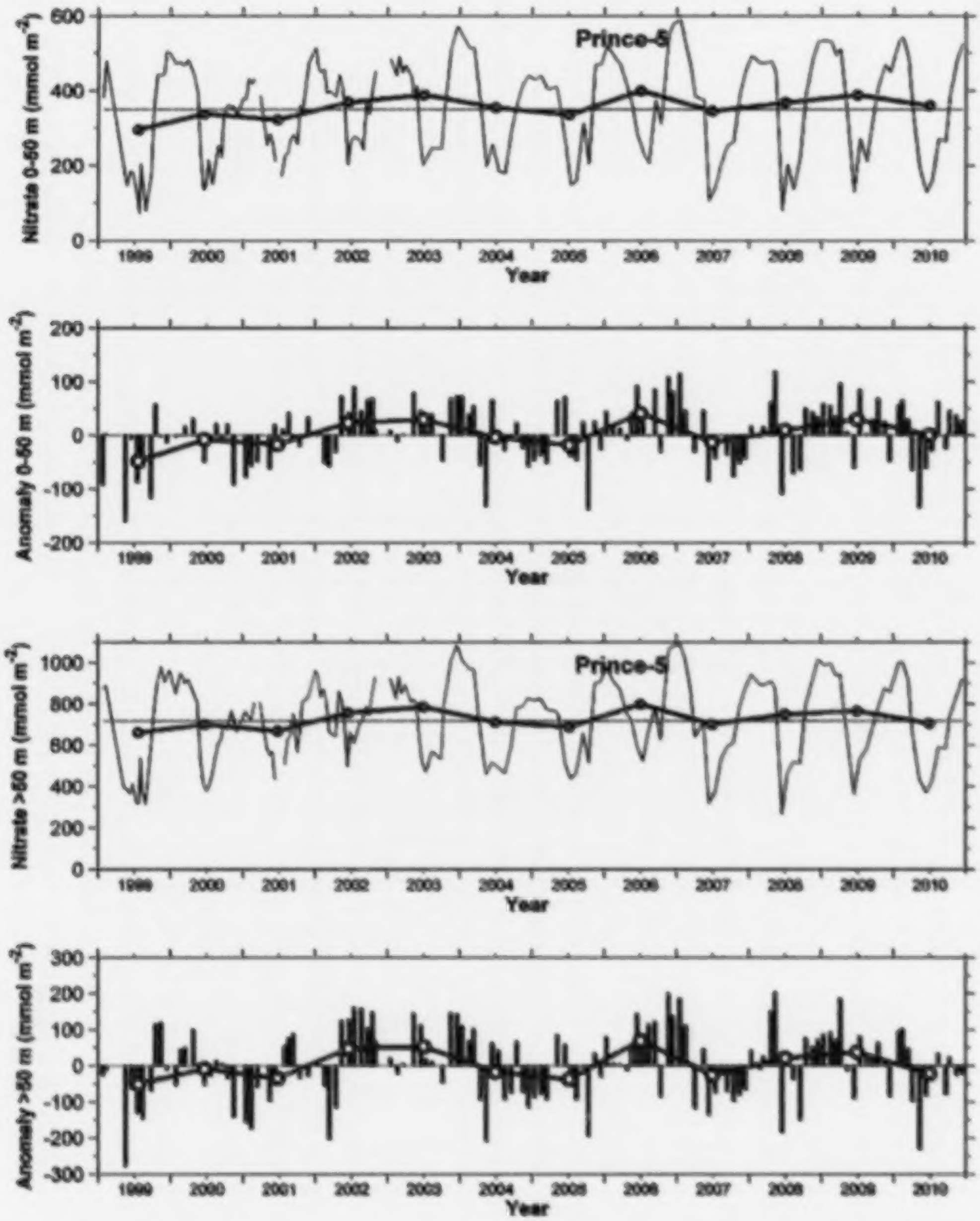


Figure 9b. Nitrate inventories at the Prince-5 fixed station, 1999-2010. Top 2 panels: surface (0-50 m) time series with annual averages (solid line); monthly (vertical bars) and annual (solid line) anomalies. Bottom 2 panels: deep (>50 m) time series with annual averages (solid line); monthly (vertical bars) and annual (solid line) anomalies (reference period: 1999-2010). The overall mean is shown as a horizontal line in the first and third panels.

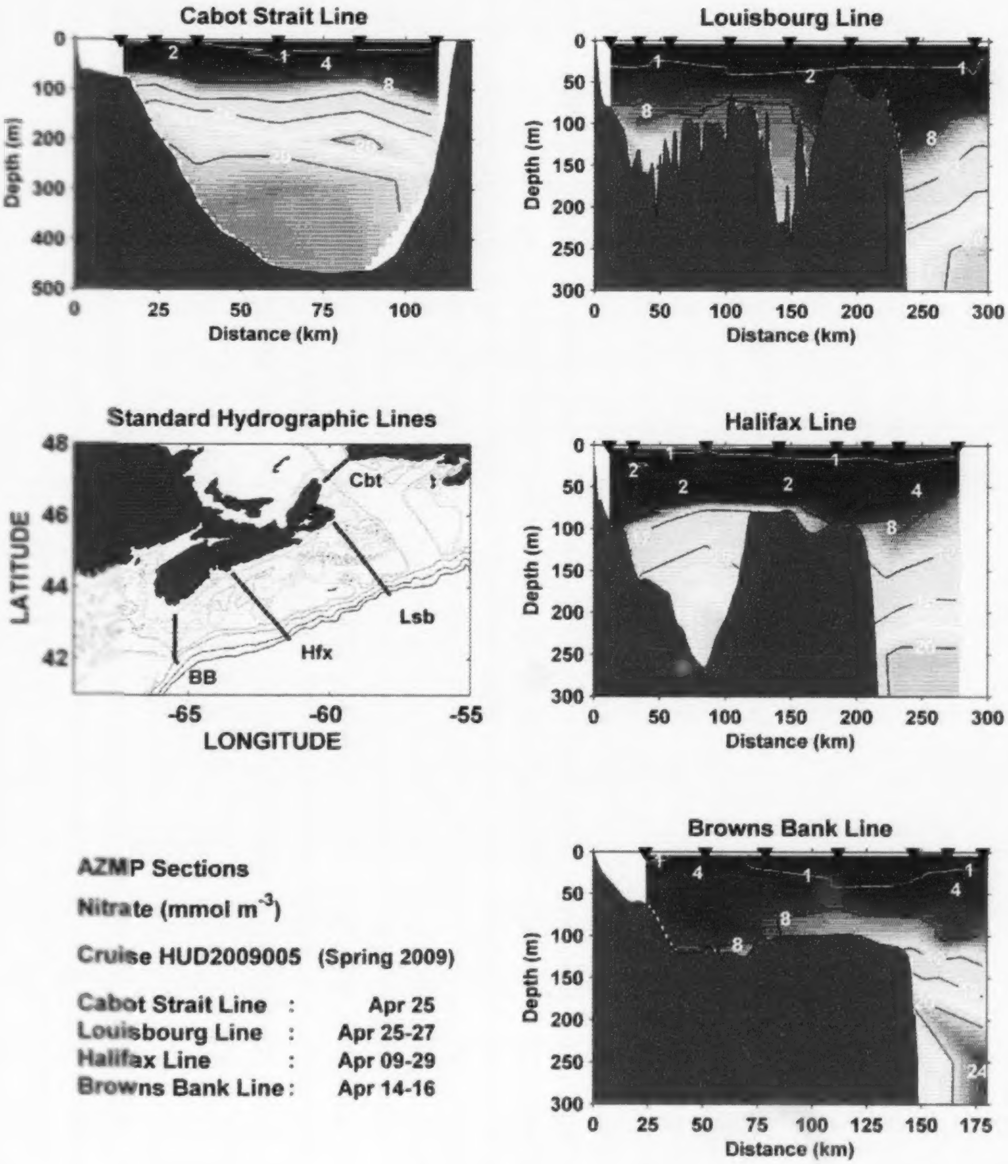


Figure 10a. Vertical nitrate structure along the Scotian Shelf sections during the spring survey in 2009.

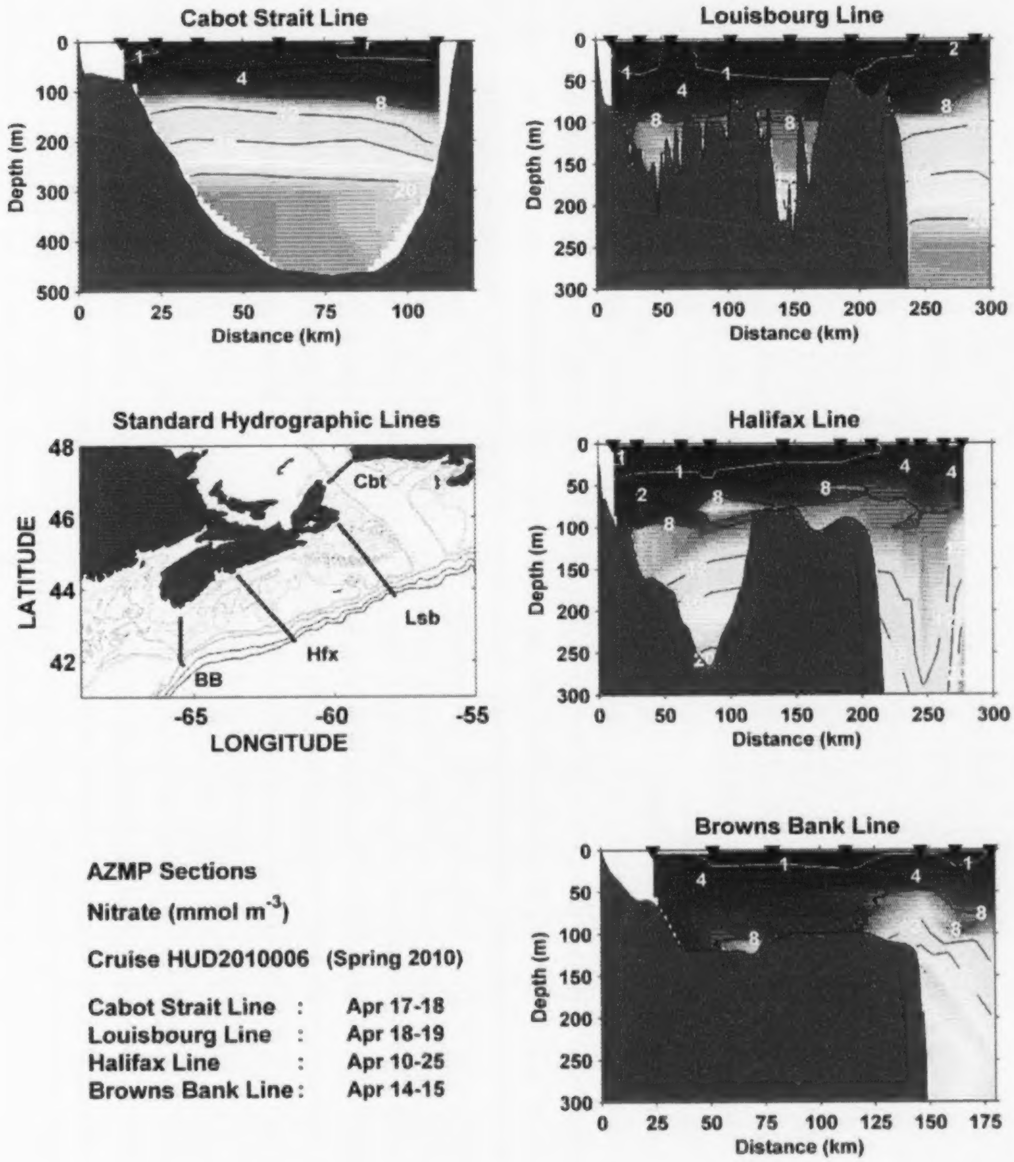


Figure 10b. Vertical nitrate structure along the Scotian Shelf sections during the spring survey in 2010.

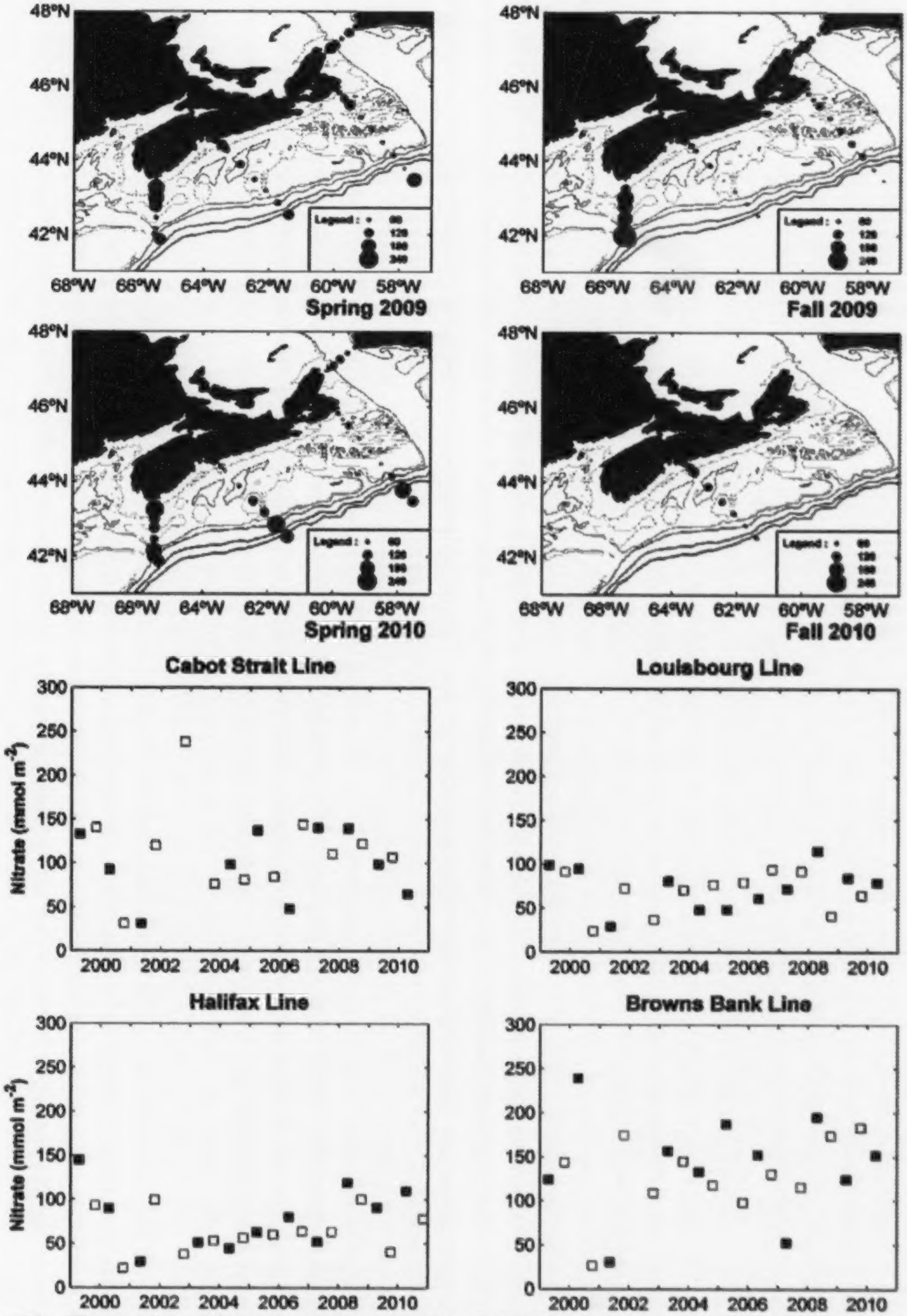


Figure 11a. Time series of line-averaged inventories of nitrate in the upper water column (0-50 m) for the spring and fall Scotian Shelf sections, 1999-2010. Filled squares = spring, open squares = fall.

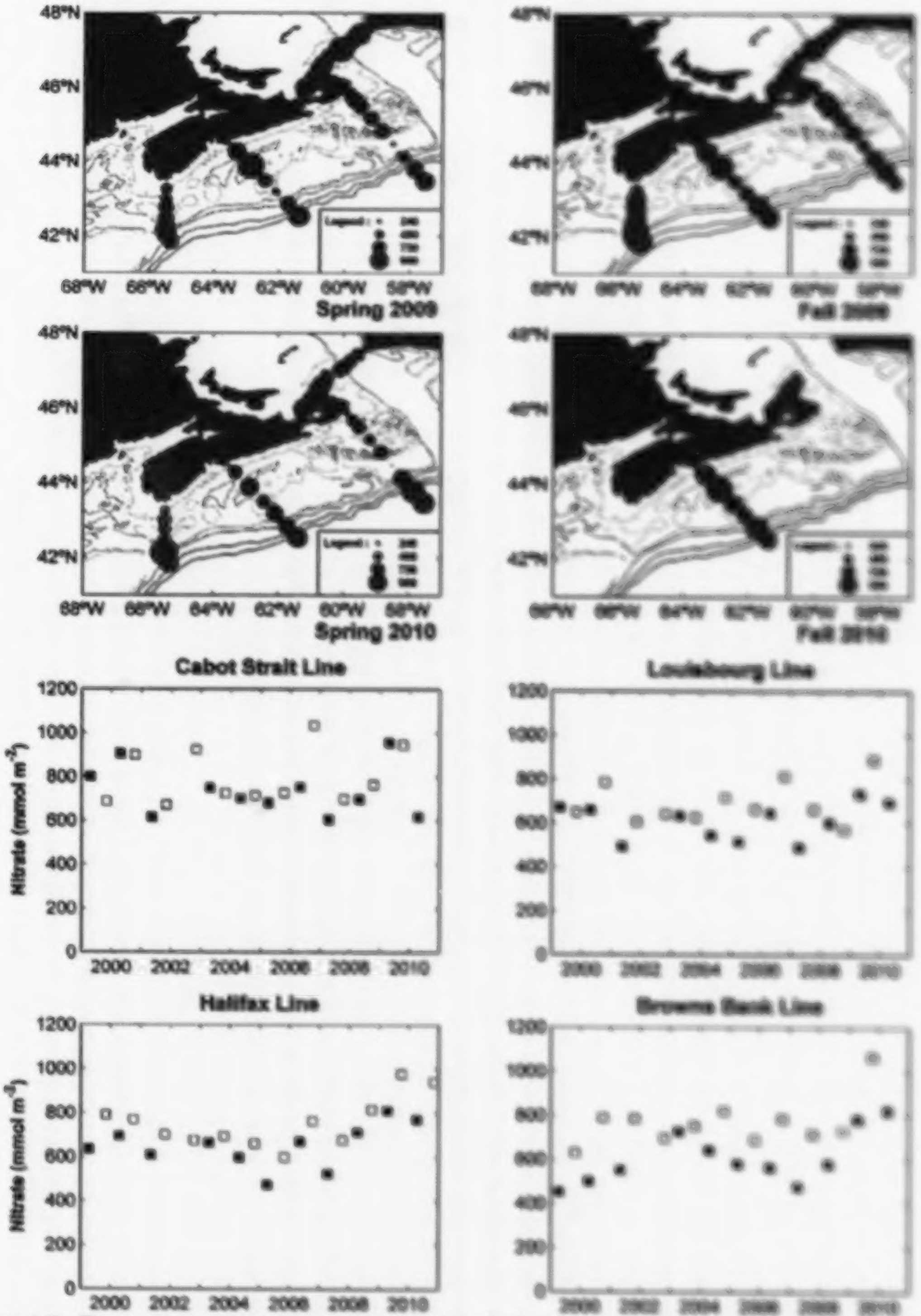


Figure 11b. Time series of line-averaged inventories of nitrate in deep waters (>50 m) for the spring and fall Scotian Shelf sections, 1999-2010. Symbols as in Figure 11a.

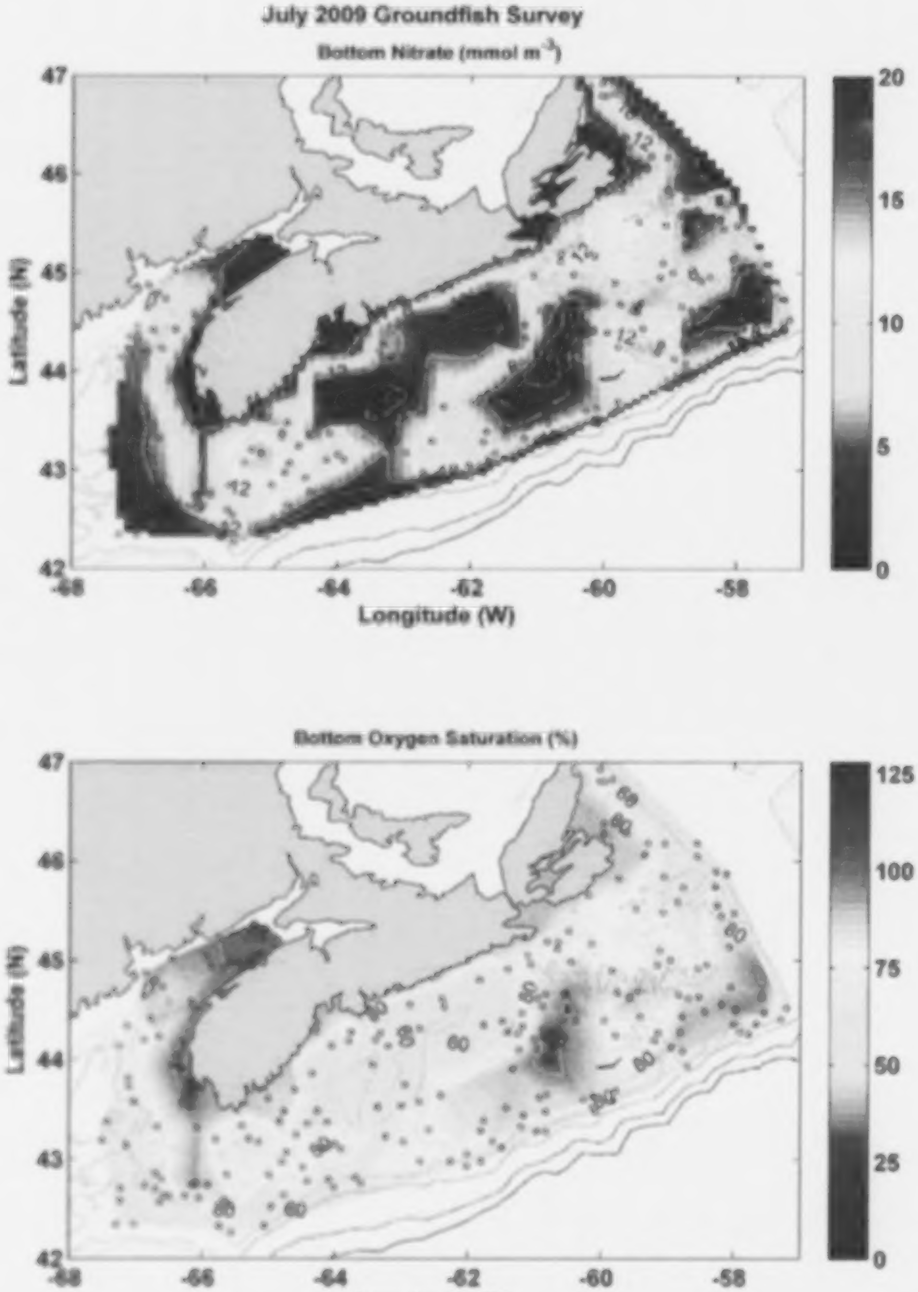
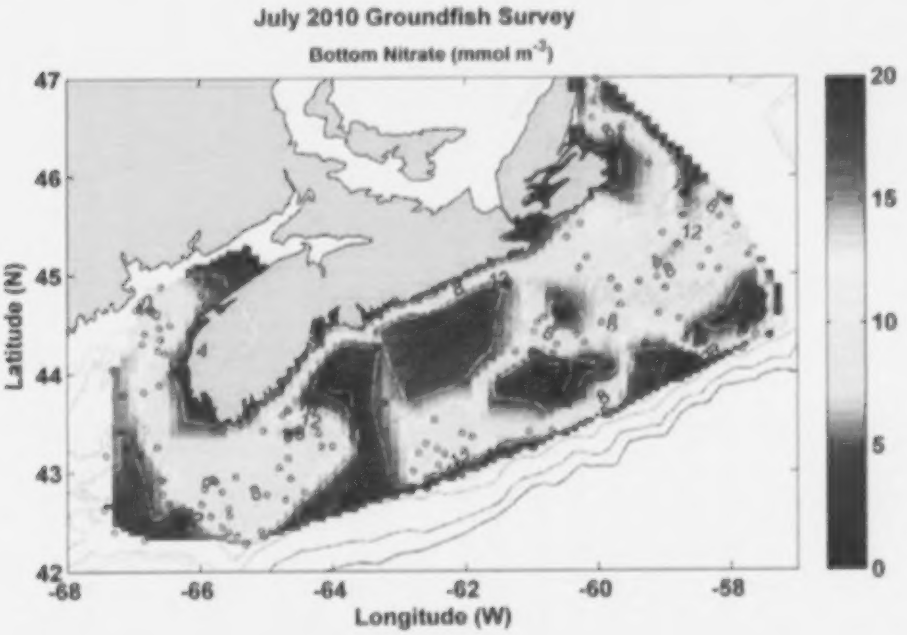


Figure 12a. Bottom nitrate concentrations (upper panel) and oxygen saturation (lower panel) on the Scotian Shelf during the annual July trawl (groundfish) survey in 2009.



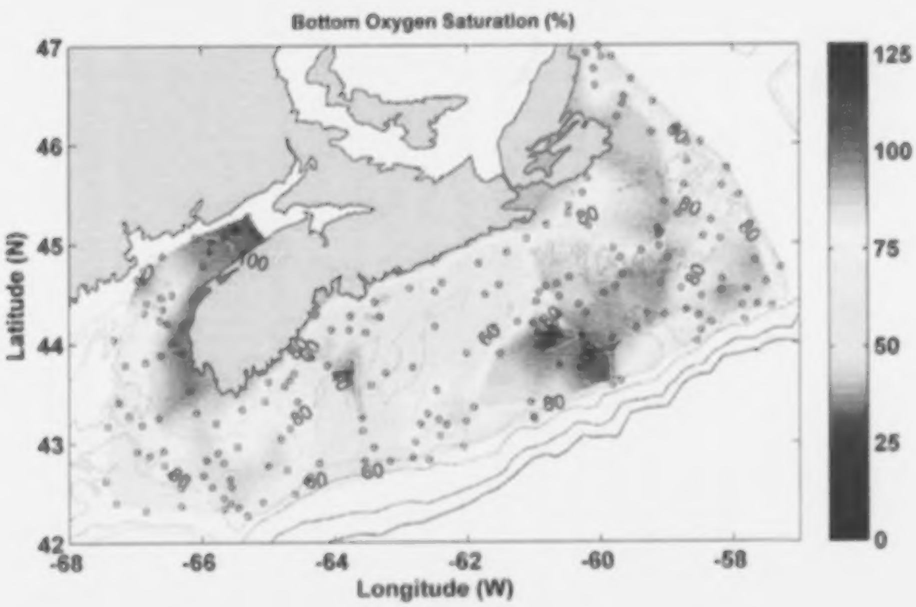


Figure 12b. Bottom nitrate concentrations (upper panel) and oxygen saturation (lower panel) on the Scotian Shelf during the annual July trawl (groundfish) survey in 2010.

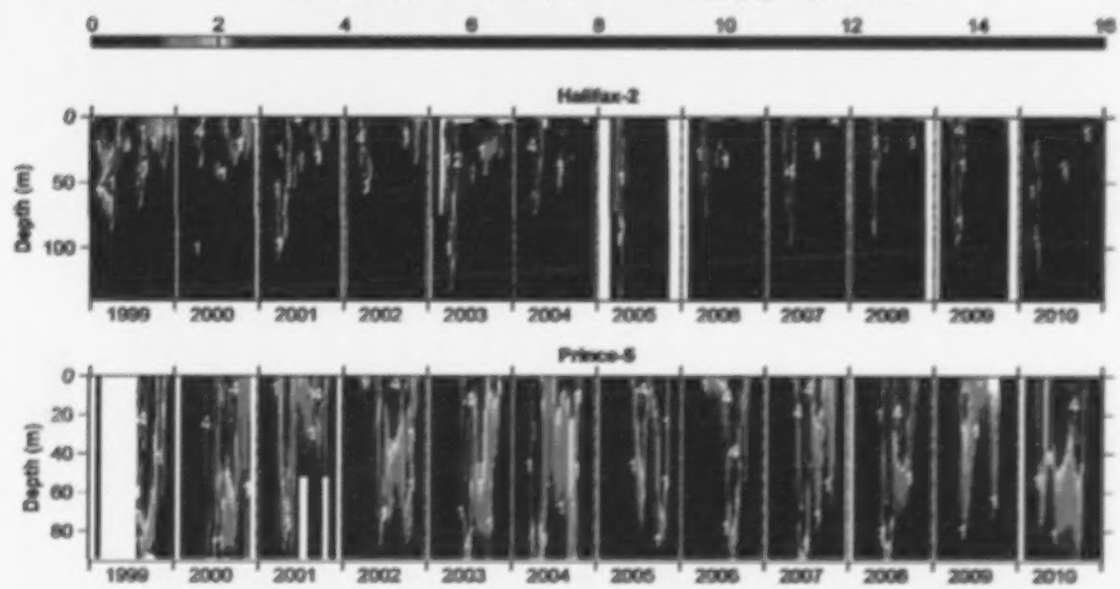


Figure 13. Time series of vertical chlorophyll structure at the Maritimes fixed stations, 1999-2010. Color scale chosen

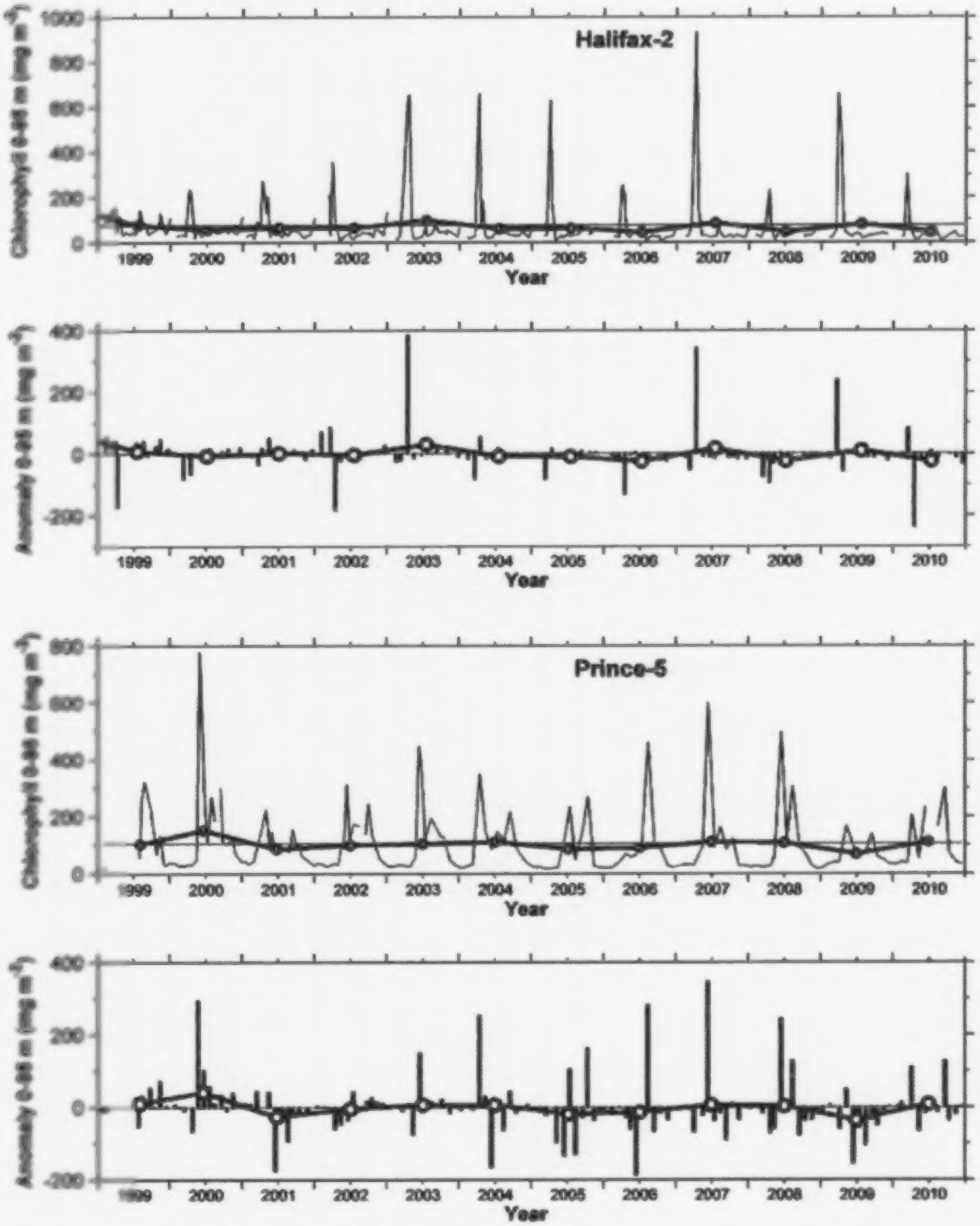


Figure 14. Chlorophyll inventories (0-100 m) at the Maritimes fixed station, 1999-2010. Top 2 panels: Halifax-2 time series with annual averages (solid line); monthly (vertical bars) and annual (solid line) anomalies. Bottom 2 panels: Prince-5 time series with annual averages (solid line); monthly (vertical bars) and annual (solid line) anomalies (reference period: 1999-2010). The overall mean is shown as a horizontal line in the first and third panels.

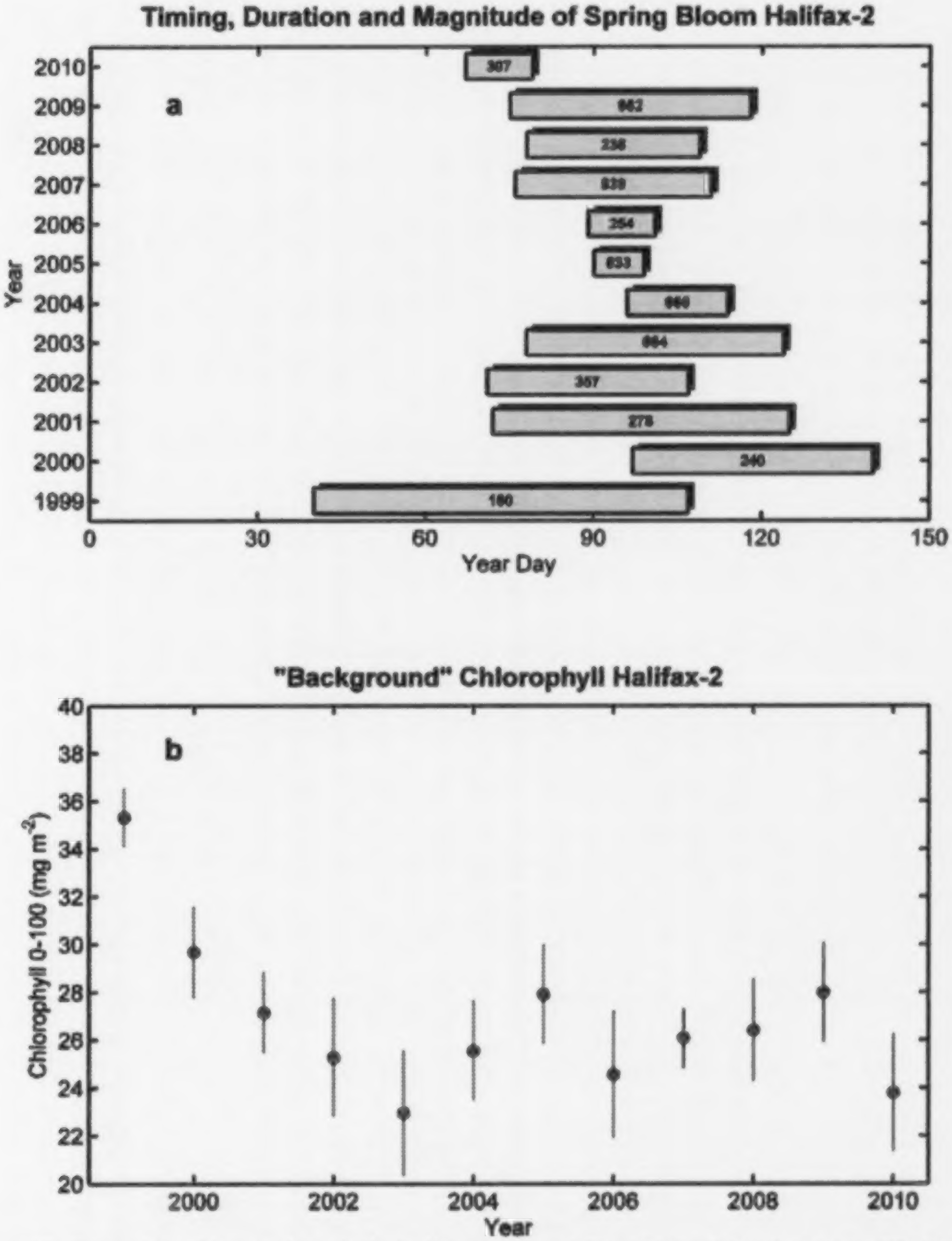


Figure 15. Dynamics of the spring phytoplankton bloom at the Halifax-2 fixed station, 1999-2010: (a) timing, duration (based on 40 mg CHL m^{-2} threshold for determining start and end of the bloom), and magnitude (numbers inside horizontal bars); (b) "background" chlorophyll levels, i.e. outside of spring bloom periods based on the 0-100m integral (annual averages +/- SE, line = least squares linear regression).

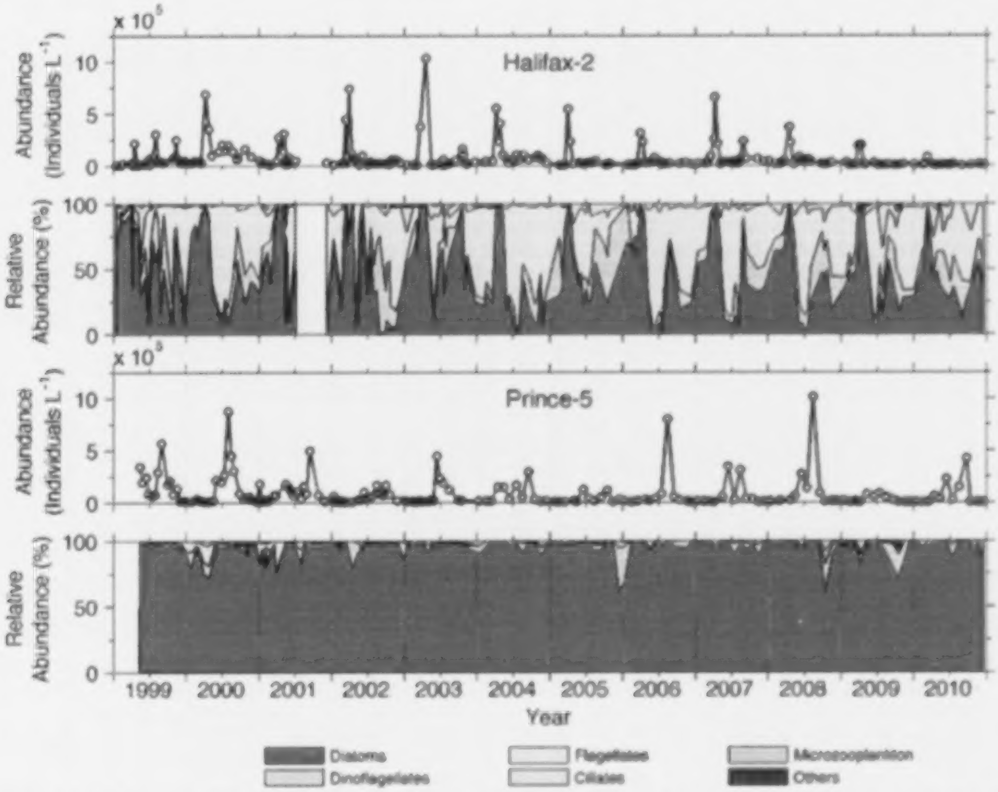


Figure 16. Time series of microplankton (phytoplankton and protists) abundance and community composition at the Maritimes fixed stations, 1999-2010.

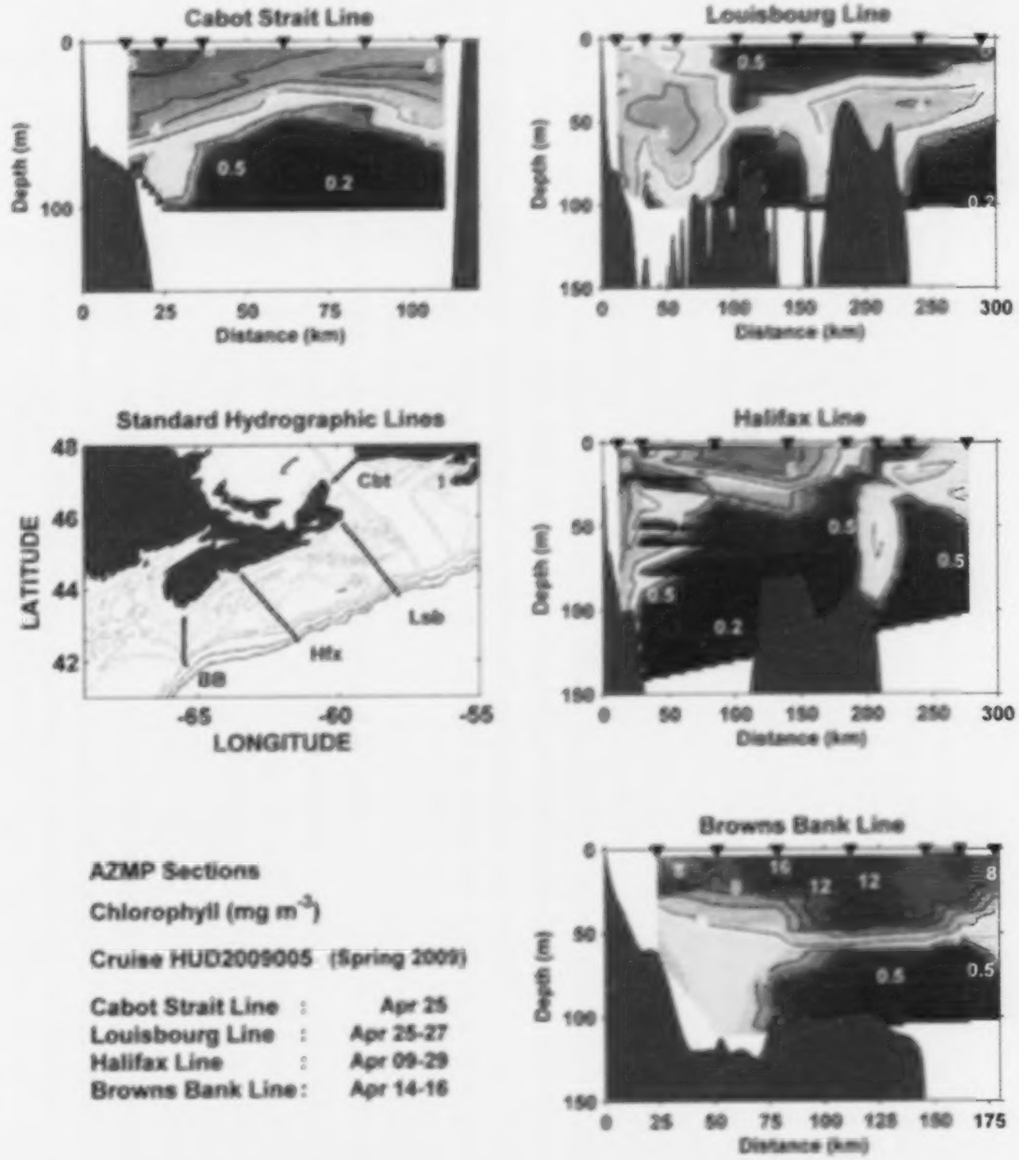


Figure 17a. Vertical chlorophyll structure along the Scotian Shelf sections during the spring survey in 2009.

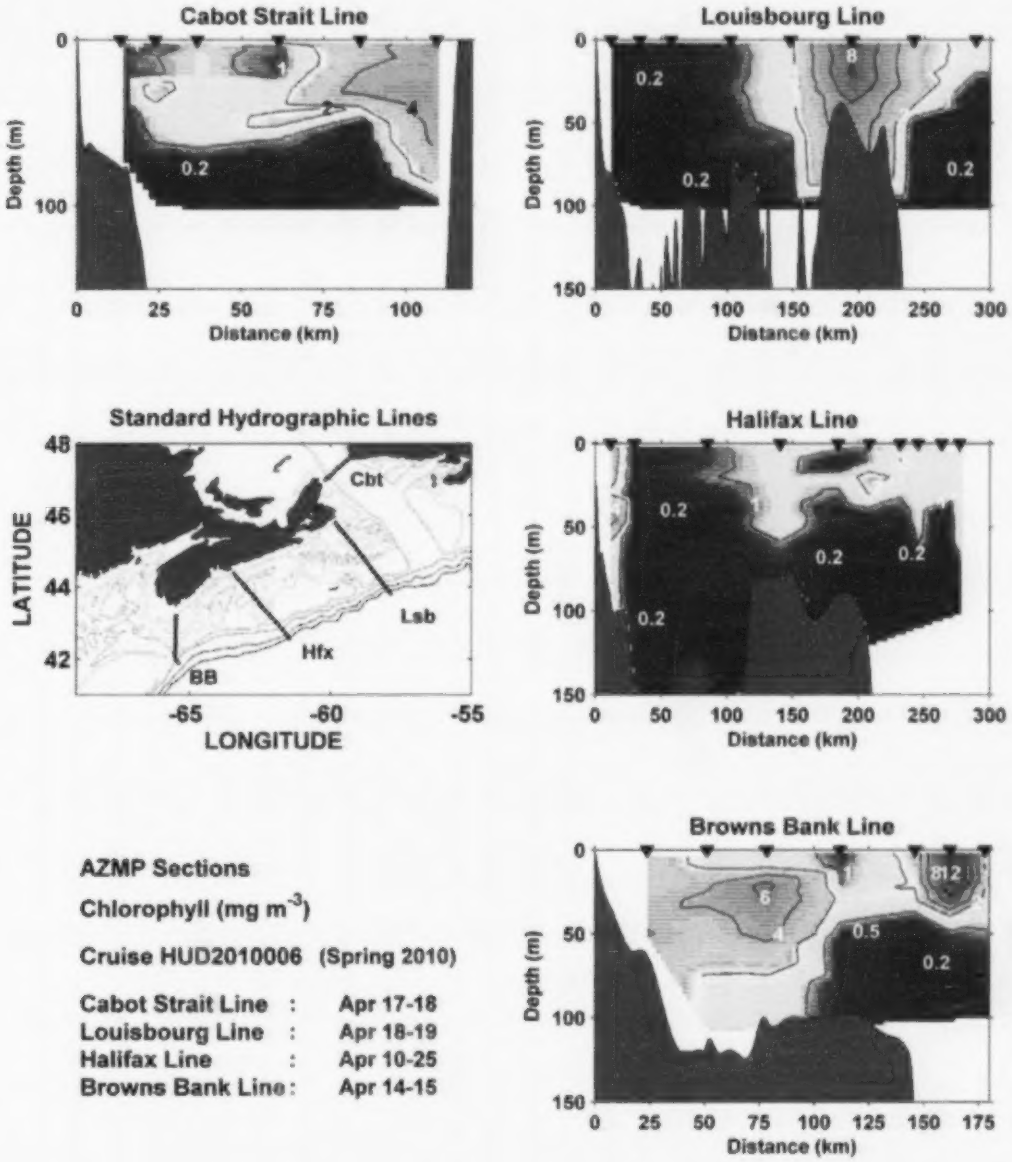


Figure 17b. Vertical chlorophyll structure along the Scotian Shelf sections during the spring survey in 2010.

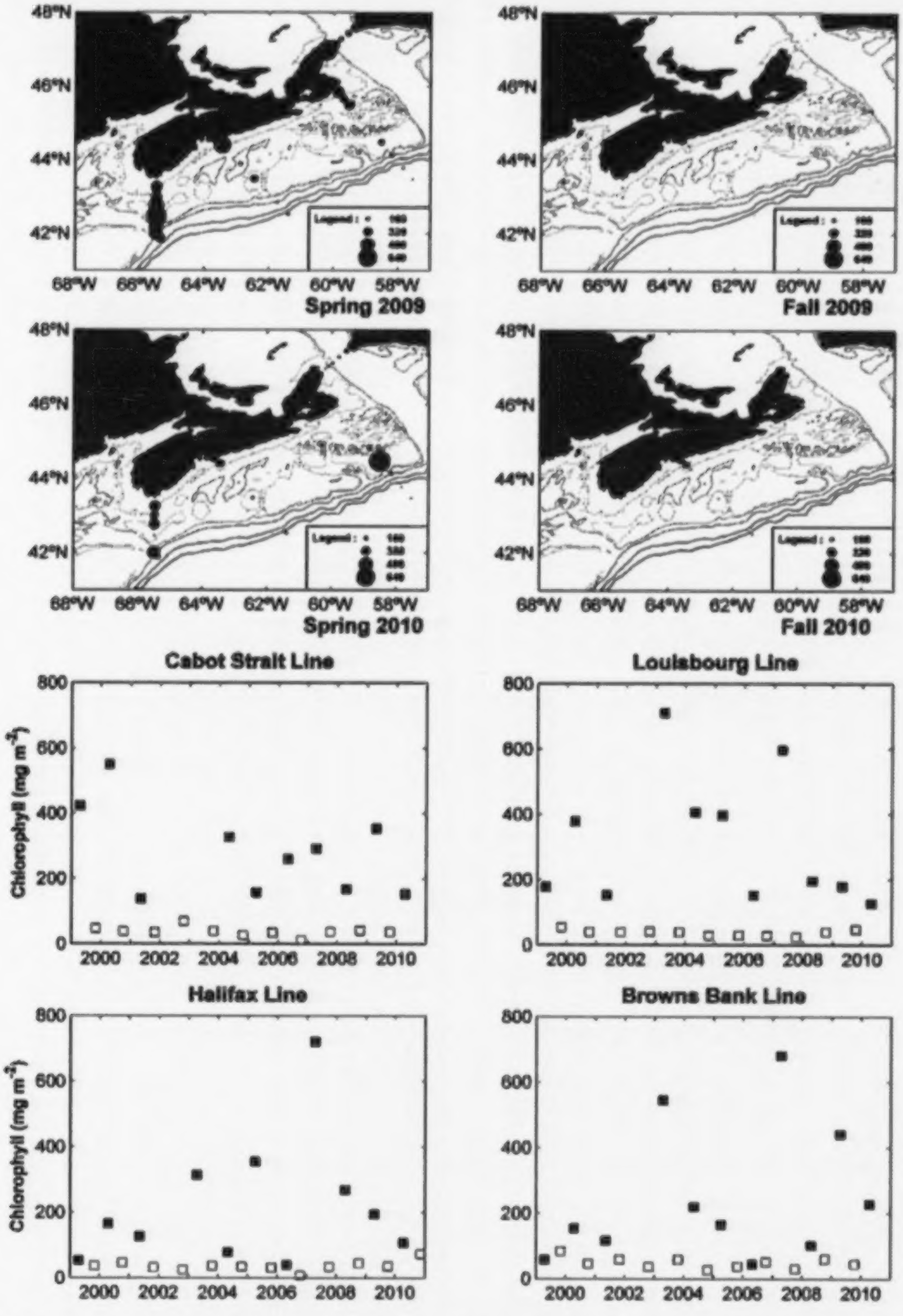


Figure 18. Time series of line-averaged inventories of chlorophyll in the upper water column (0-100 m) for the spring and fall Scotian Shelf sections, 1999-2010. Symbols as in Figure 11a.

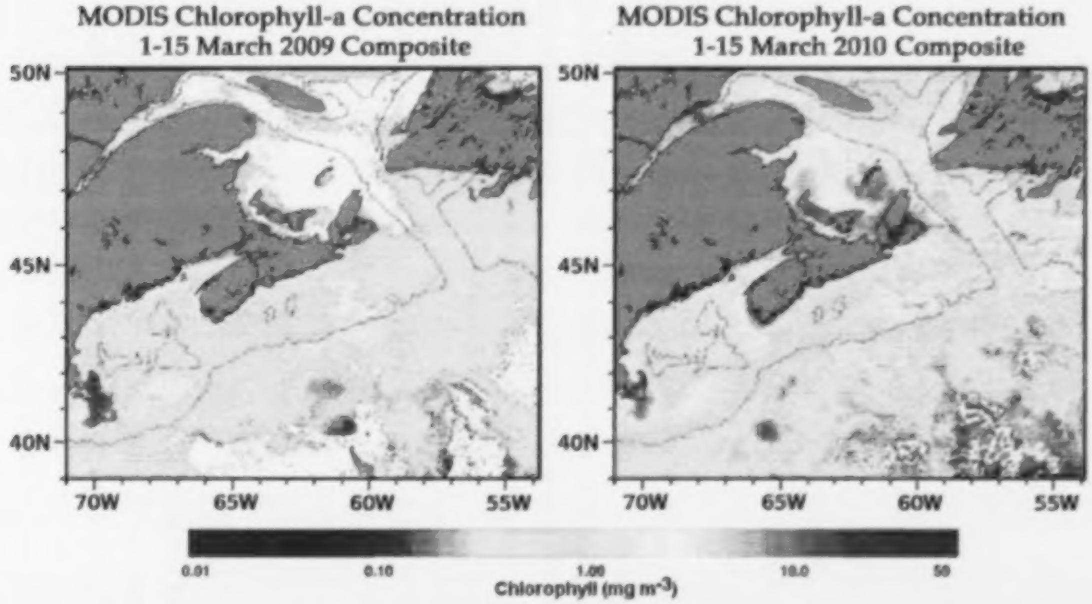


Figure 19. MODIS twice-monthly composite images of surface chlorophyll in the Maritimes/Gulf regions: during the spring (March) shelf surveys in 2009 and 2010.

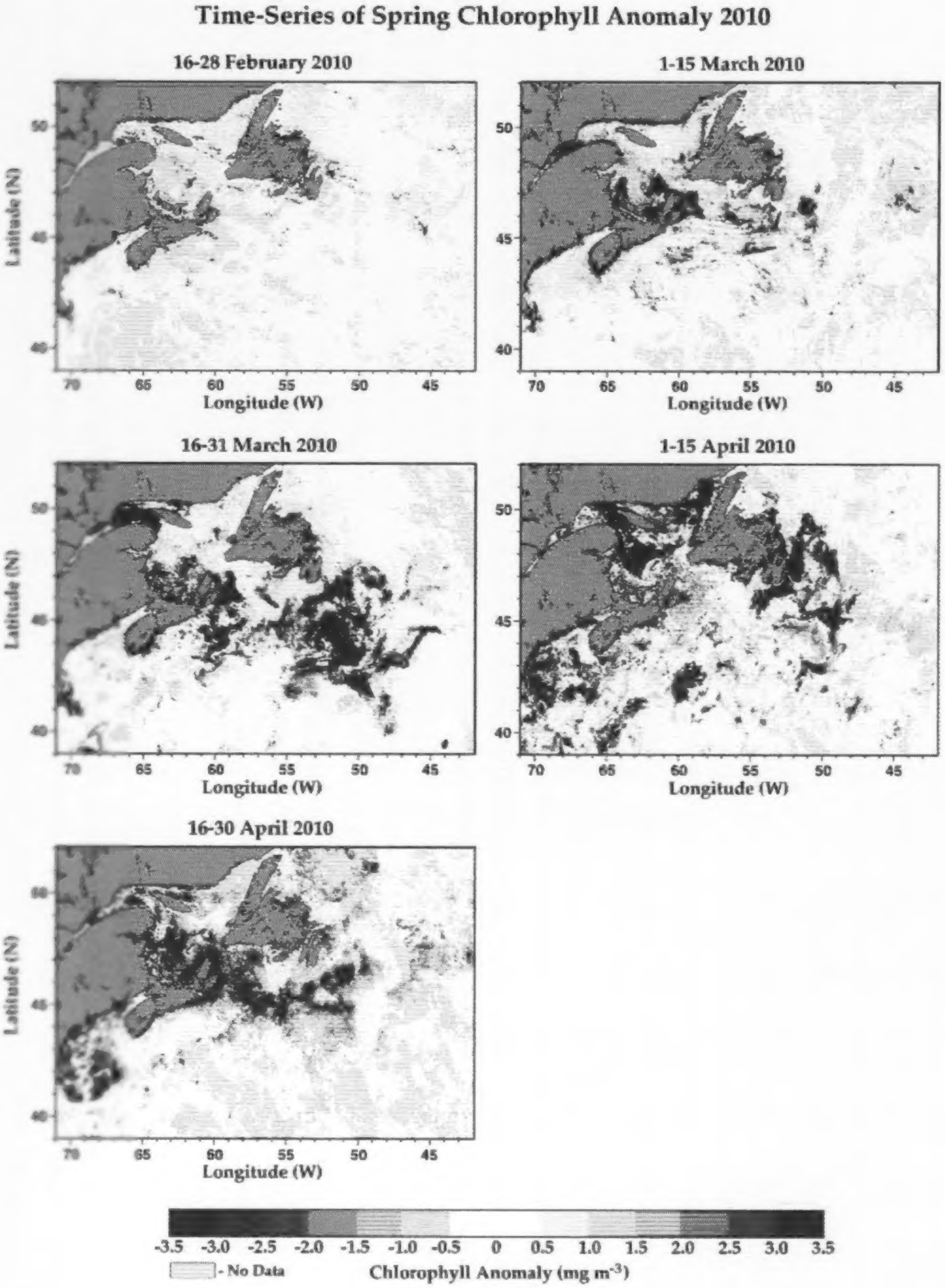


Figure 20. Surface chlorophyll anomalies from MODIS twice monthly composite images in the Maritimes/Gulf regions between February and April, 2010. Reference period: 2003-2007.

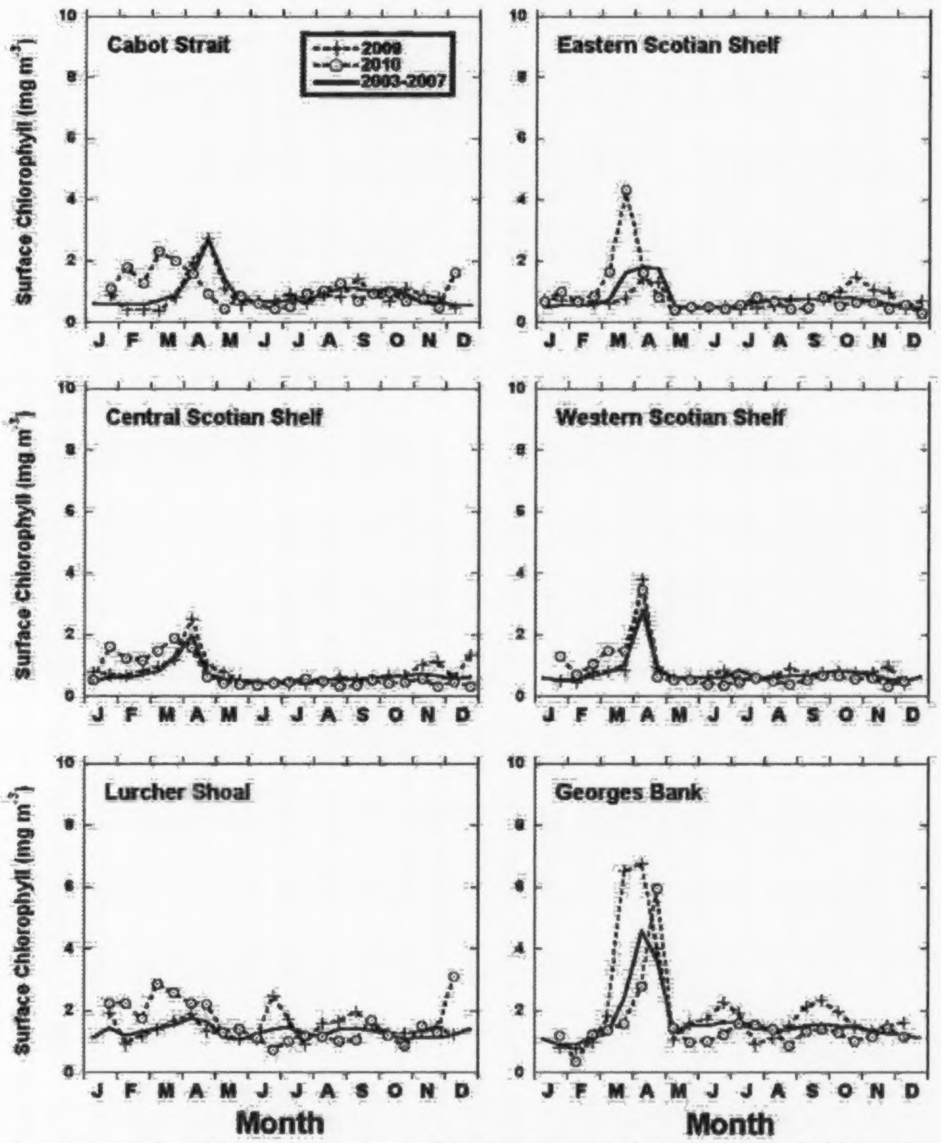


Figure 21. Seasonal variability in surface chlorophyll concentrations (from MODIS twice monthly composites) for the statistical sub-regions of the Maritimes Region (see Figure 4). Solid lines represent mean (2003-2007) levels, dashed lines with crosses represent 2009 levels, dashed lines with circles represent 2010.

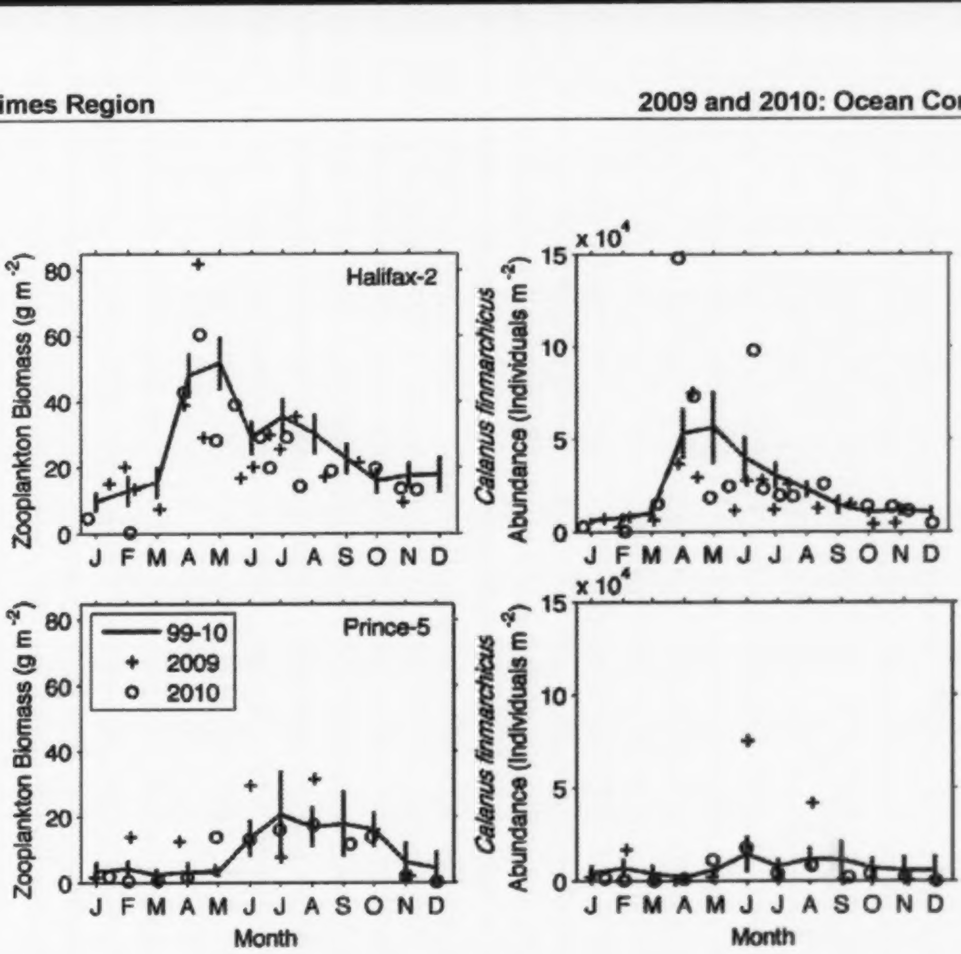


Figure 22. Comparison of 2009 (+) and 2010 (o) data with mean conditions from 1999-2010 (solid line) at the Maritimes fixed stations. Left panels: zooplankton biomass (surface to bottom). Right panels: Calanus finmarchicus *abundance (all copepodite and adult stages, surface to bottom). Vertical lines are 95% confidence intervals of the observations.*

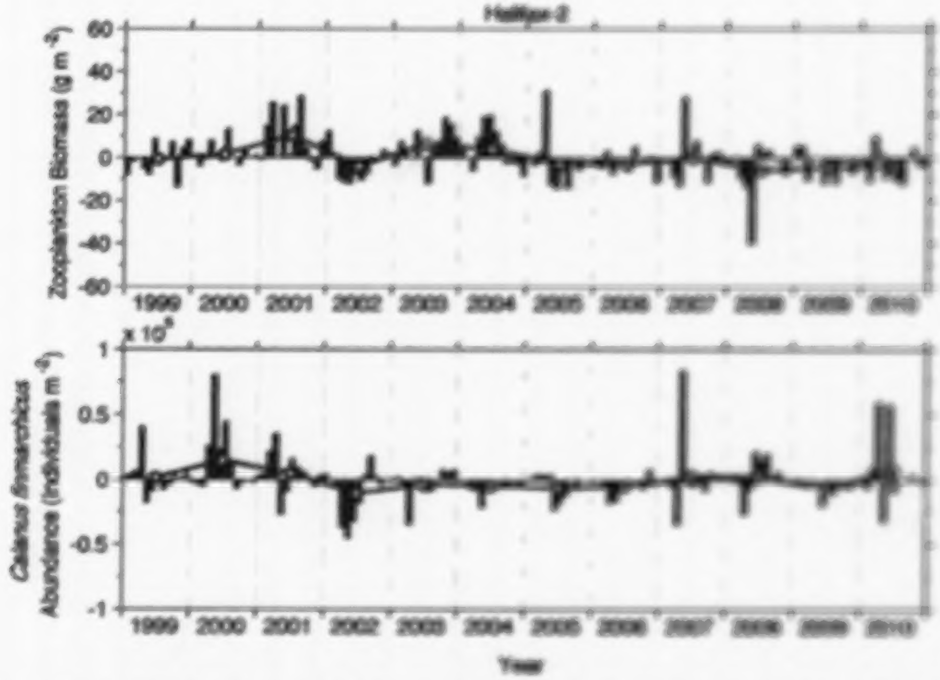


Figure 23a. Zooplankton biomass and Calanus finmarchicus abundance anomalies at Halifax-2, with monthly anomalies (vertical bars) and annual anomalies (open circle) (reference period: 1999-2010).

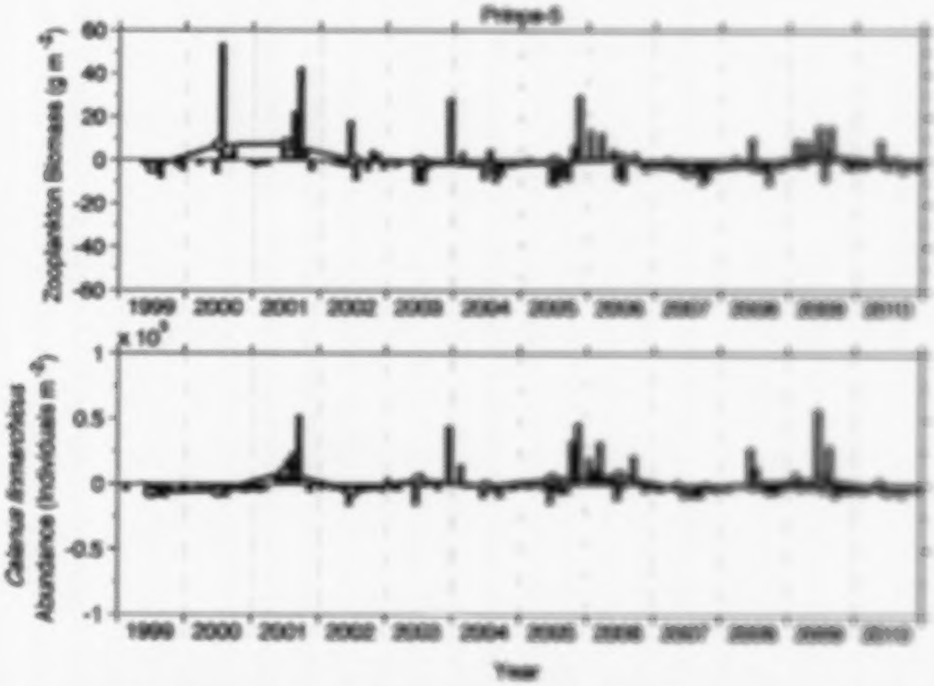


Figure 23b. Zooplankton biomass and Calanus finmarchicus abundance anomalies at Prince-5, with monthly anomalies (vertical bars) and annual anomalies (open circle) (reference period: 1999-2010).

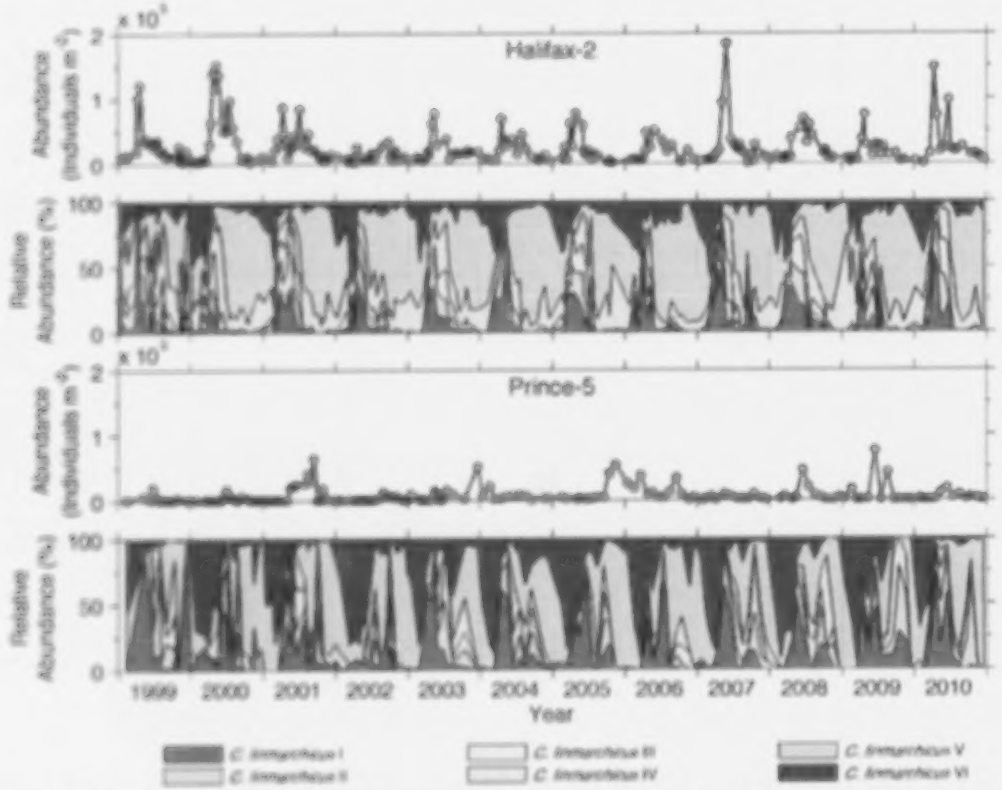


Figure 24. Time series of Calanus finmarchicus *abundance and developmental stages at the Maritimes fixed stations, 1999-2010.*

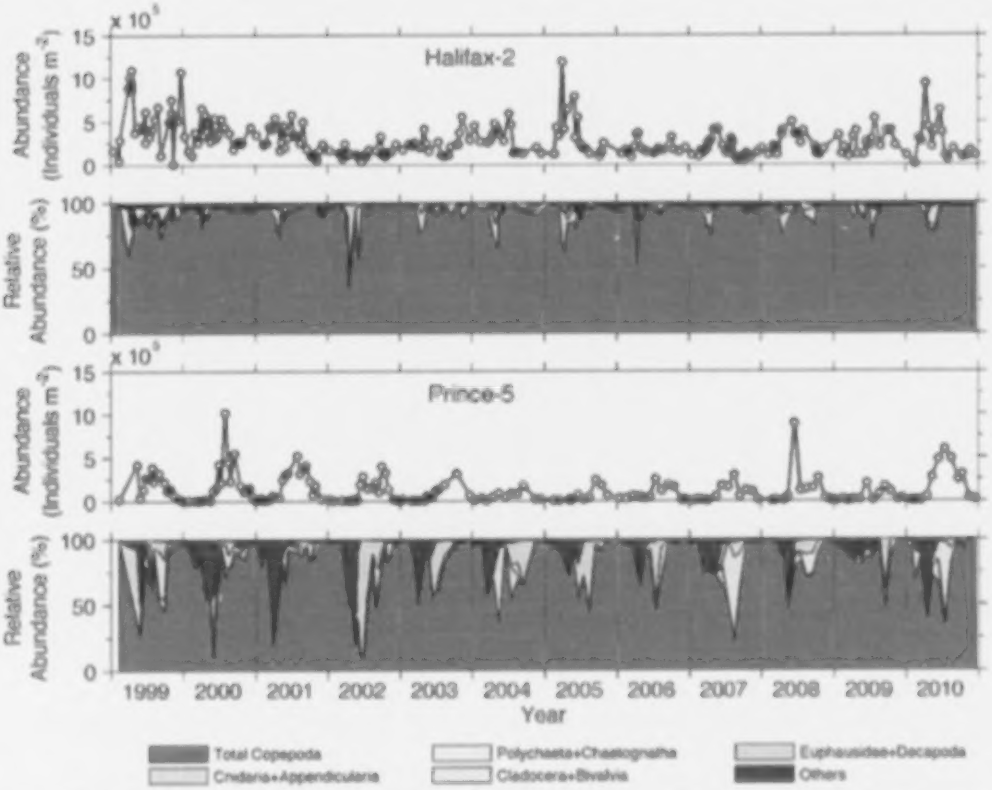


Figure 25. Time series of zooplankton (>200 µm) abundance and community composition at the Maritimes fixed stations, 1999-2010.

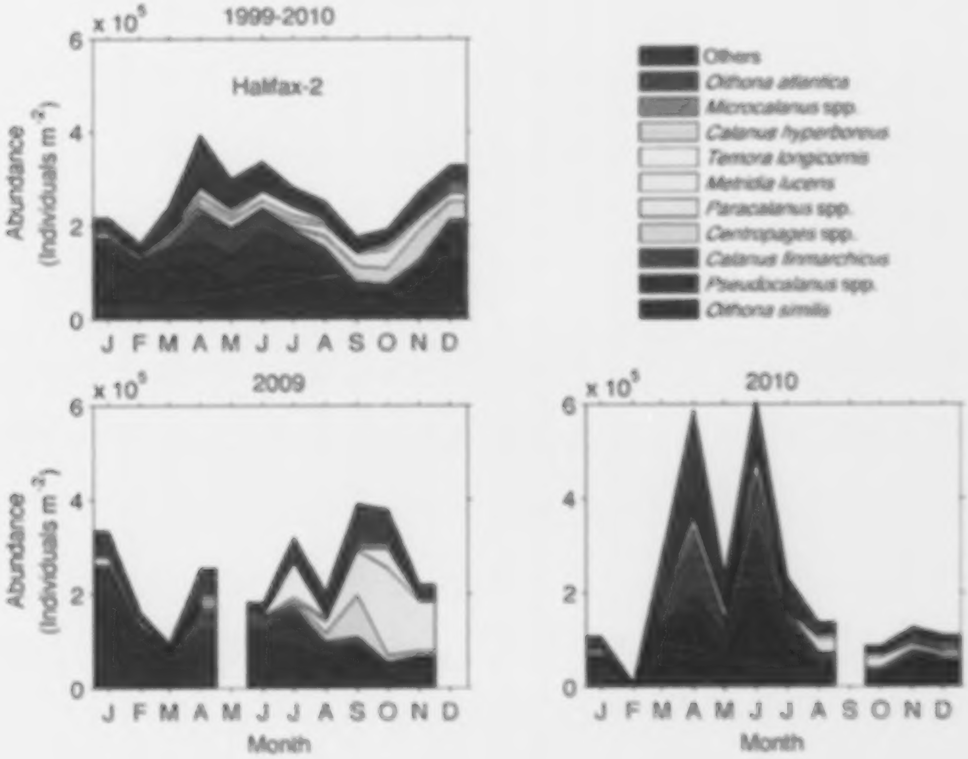


Figure 26a. Seasonal variability of dominant copepods at Halifax-2. The top 95% of copepods by abundance are shown individually; others are grouped as 'others.' The top panel is based on monthly mean abundances from 1999-2010. Bottom panels are monthly mean abundances in 2009 and 2010.

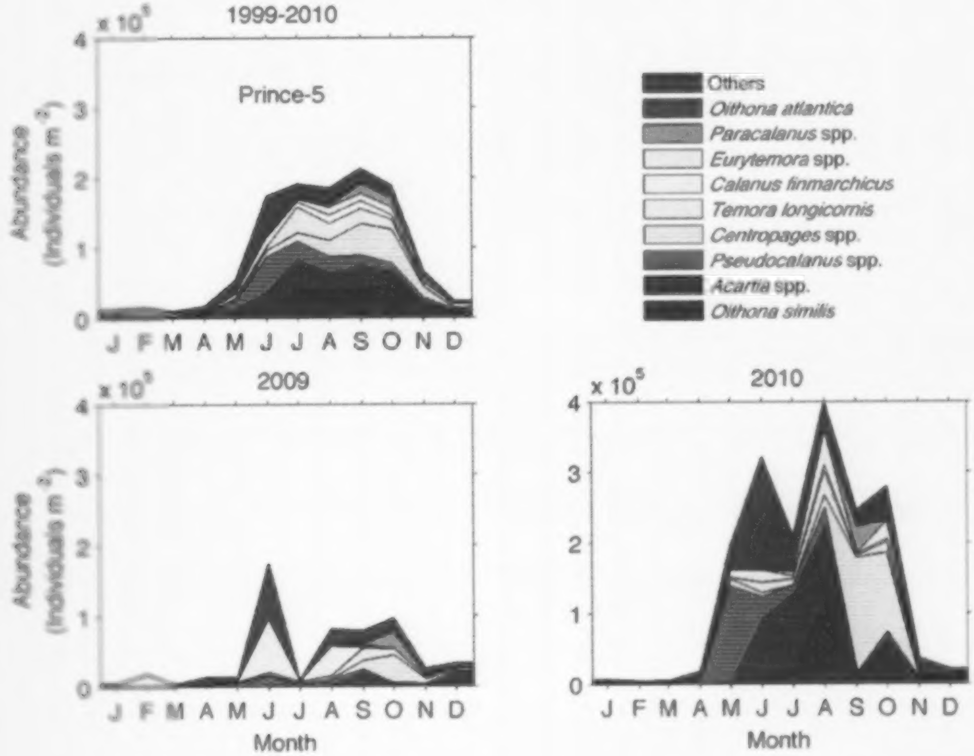


Figure 26b. Seasonal variability of dominant copepods at Prince-5. The top 95% of copepods by abundance are shown individually; others are grouped as 'others.' The top panel is based on monthly mean abundances from 1999-2010. Bottom panels are monthly mean abundances in 2009 and 2010.

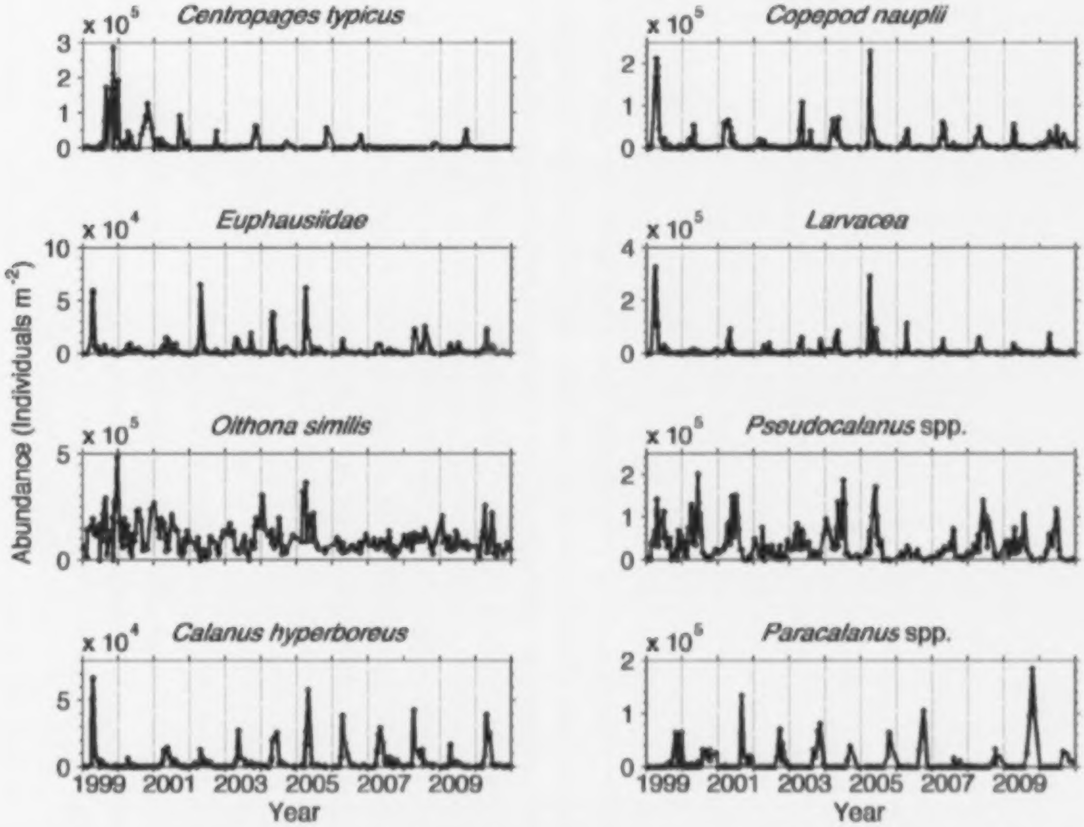


Figure 27a. Time series of 8 dominant or important zooplankton taxa from Halifax-2 for the period 1999-2010.

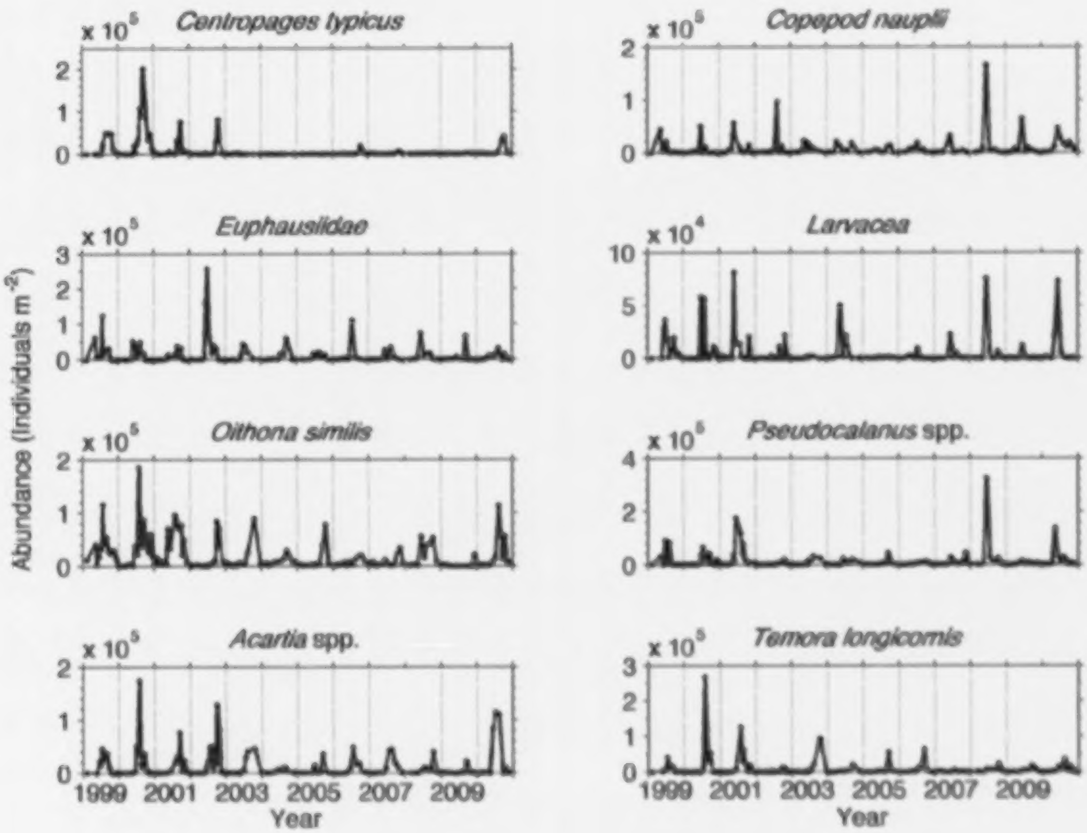


Figure 27b. Time series of 8 dominant or important zooplankton taxa from Prince-5 for the period 1999-2010.

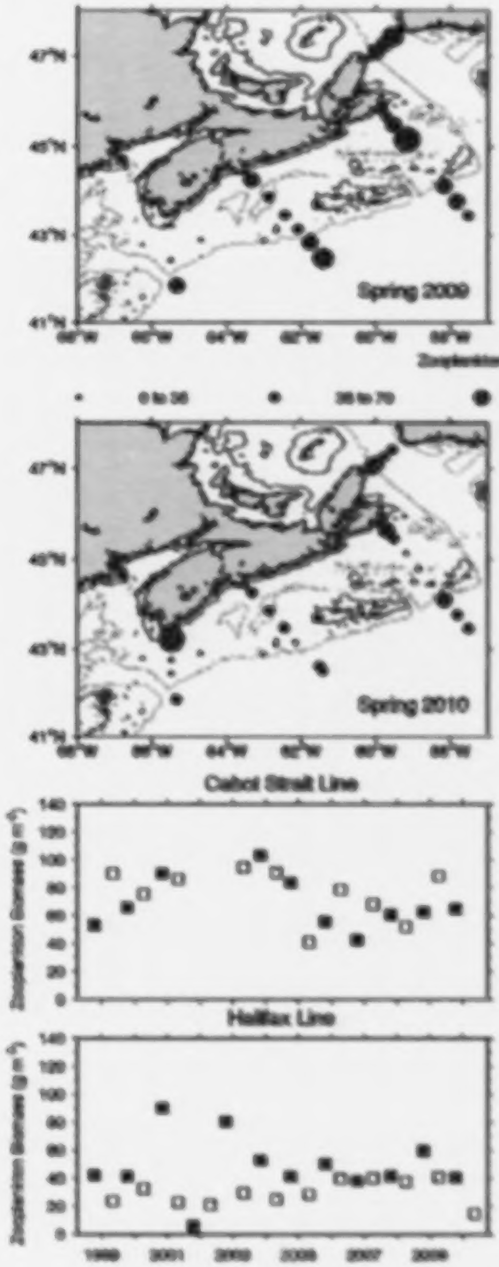


Figure 28a. Spatial distribution of zooplankton biomass (upper panels) and average zooplankton biomass on Scotian Shelf sections (lower panels) in spring and fall, 1999-2010.

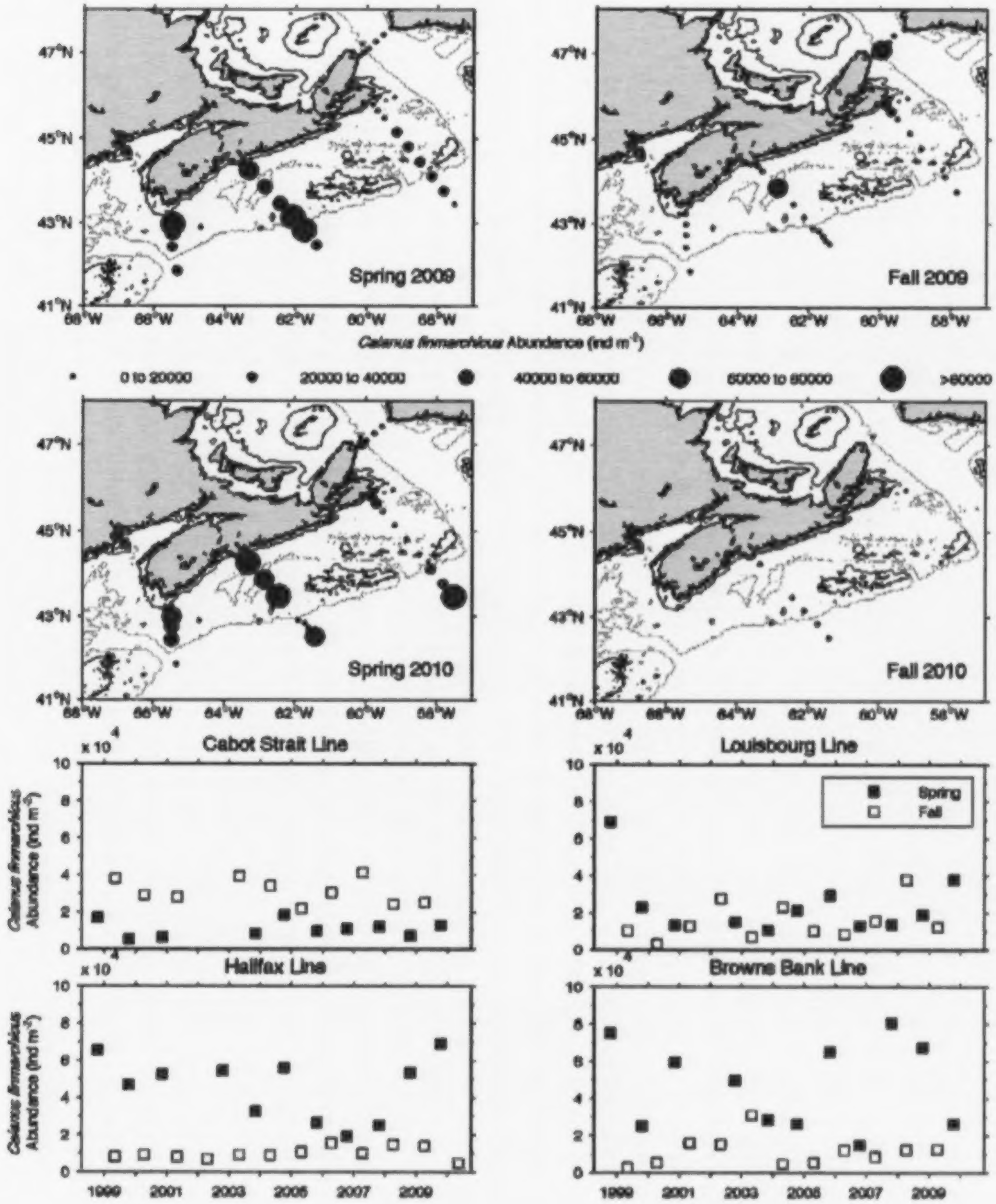


Figure 28b. Spatial distribution of Calanus finmarchicus *abundance (upper panels) and average* Calanus finmarchicus *abundance on Scotian Shelf sections (lower panels) in spring and fall, 1999-2010.*

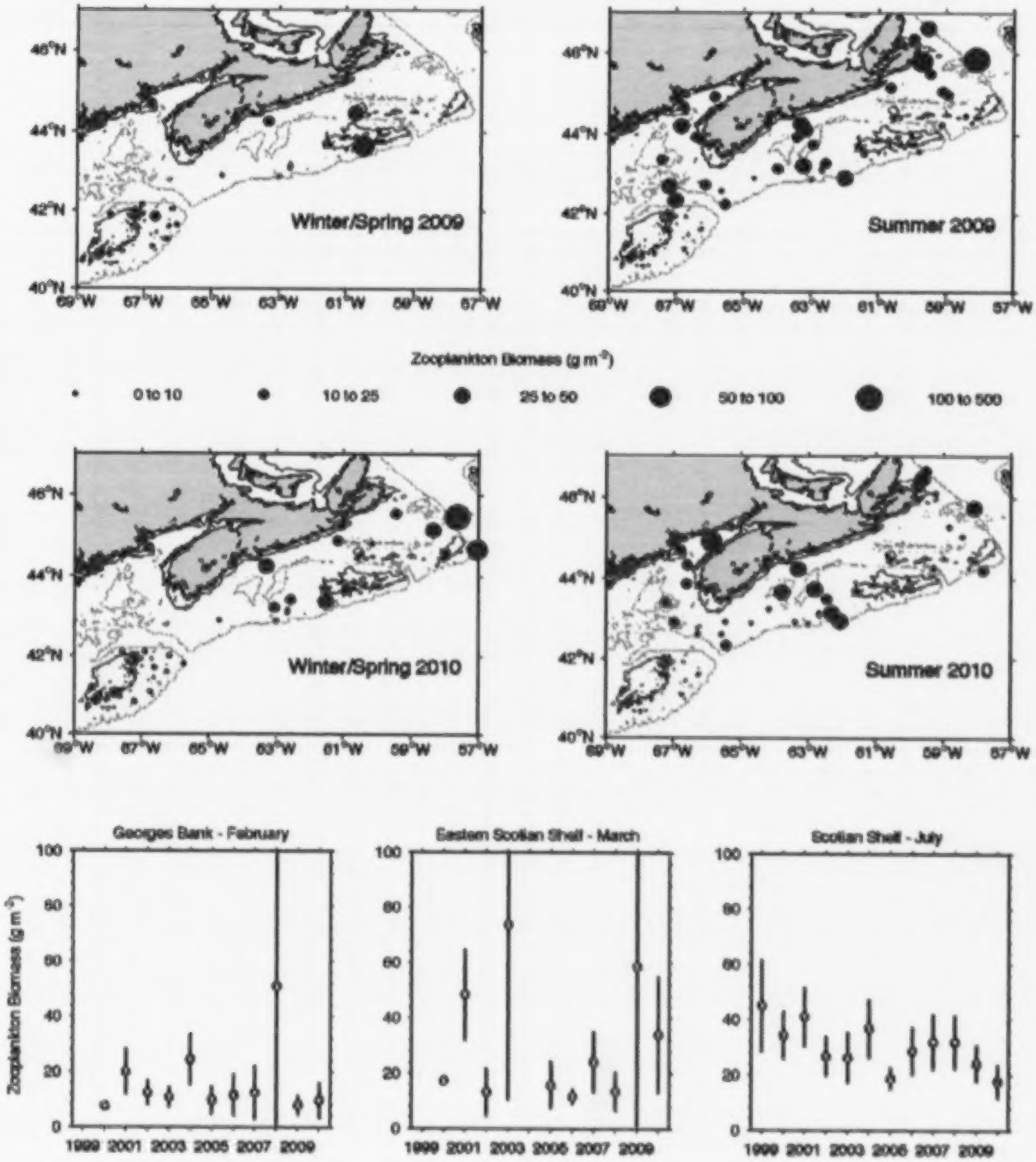


Figure 29a. Zooplankton biomass from trawl (groundfish) surveys on Georges Bank (February), the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2009 and 2010 spatial distributions, lower panels show survey mean biomass, 1999-2010 (vertical bars are standard errors).

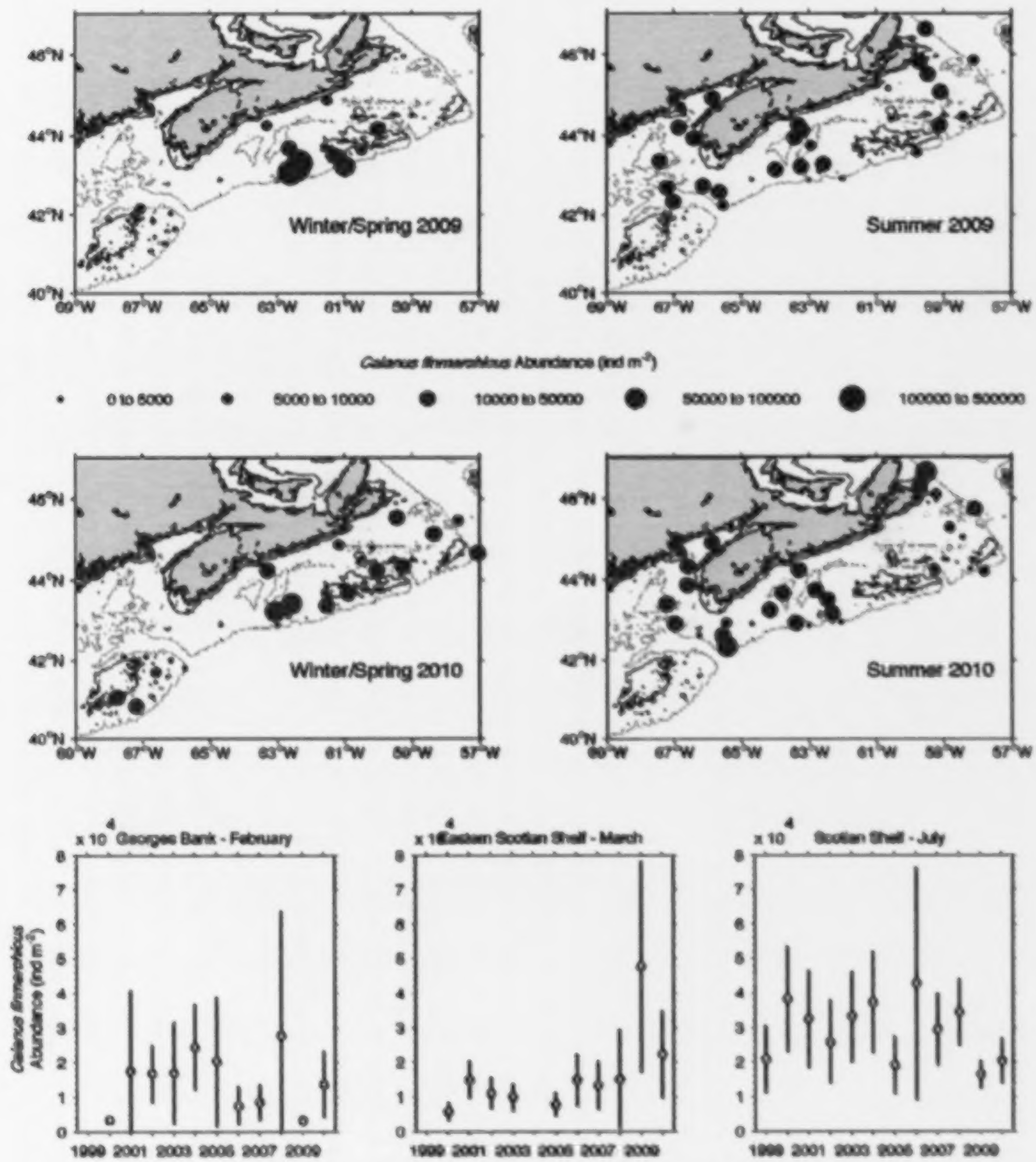


Figure 29b. Calanus finmarchicus *abundance from trawl (groundfish) surveys on Georges Bank (February), the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2009 and 2010 spatial distributions, lower panels show survey mean abundance, 1999-2010 (vertical bars are standard errors).*

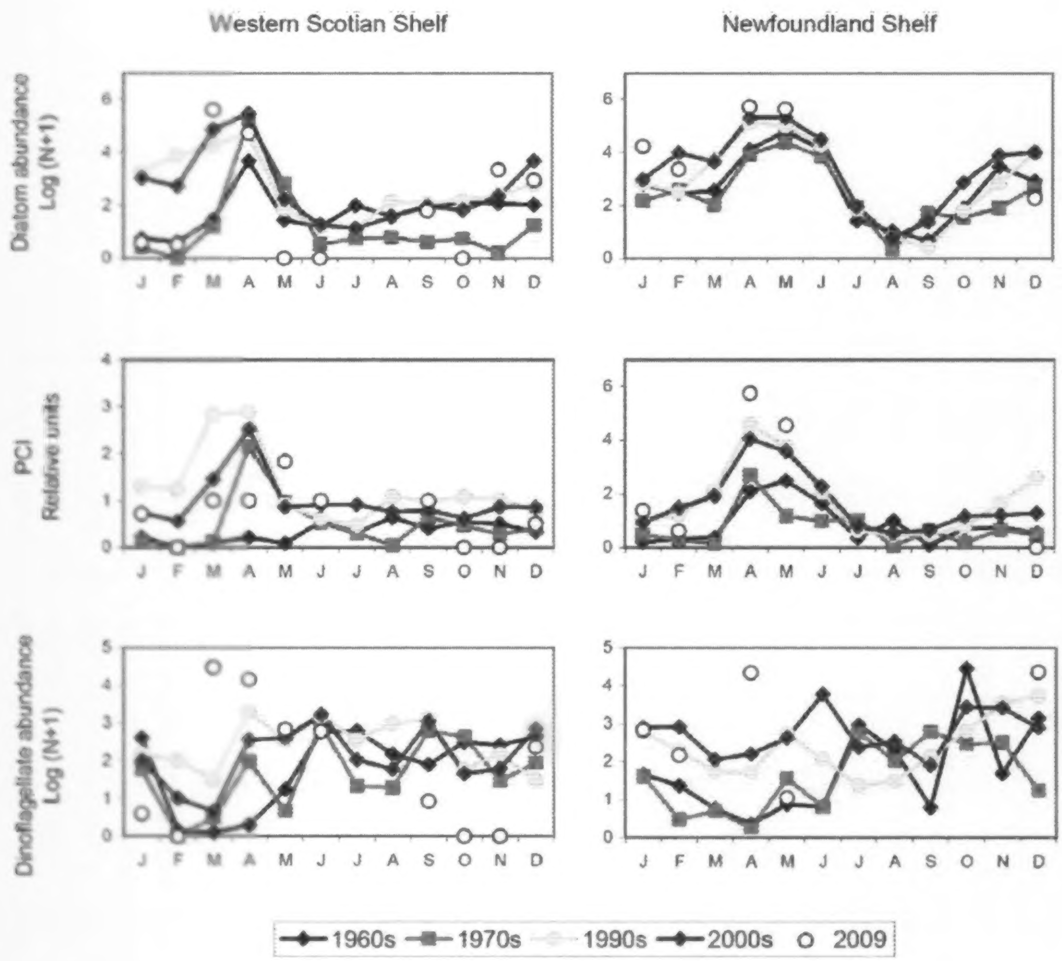


Figure 30. Monthly average abundances of phytoplankton indices on the Western Scotian Shelf and Newfoundland Shelf for the 1960s (1961-1969), the 1970s (1970-1976), the 1990s (1991-1999) and the 2000s (2000-2008). Open circles are values for 2009.

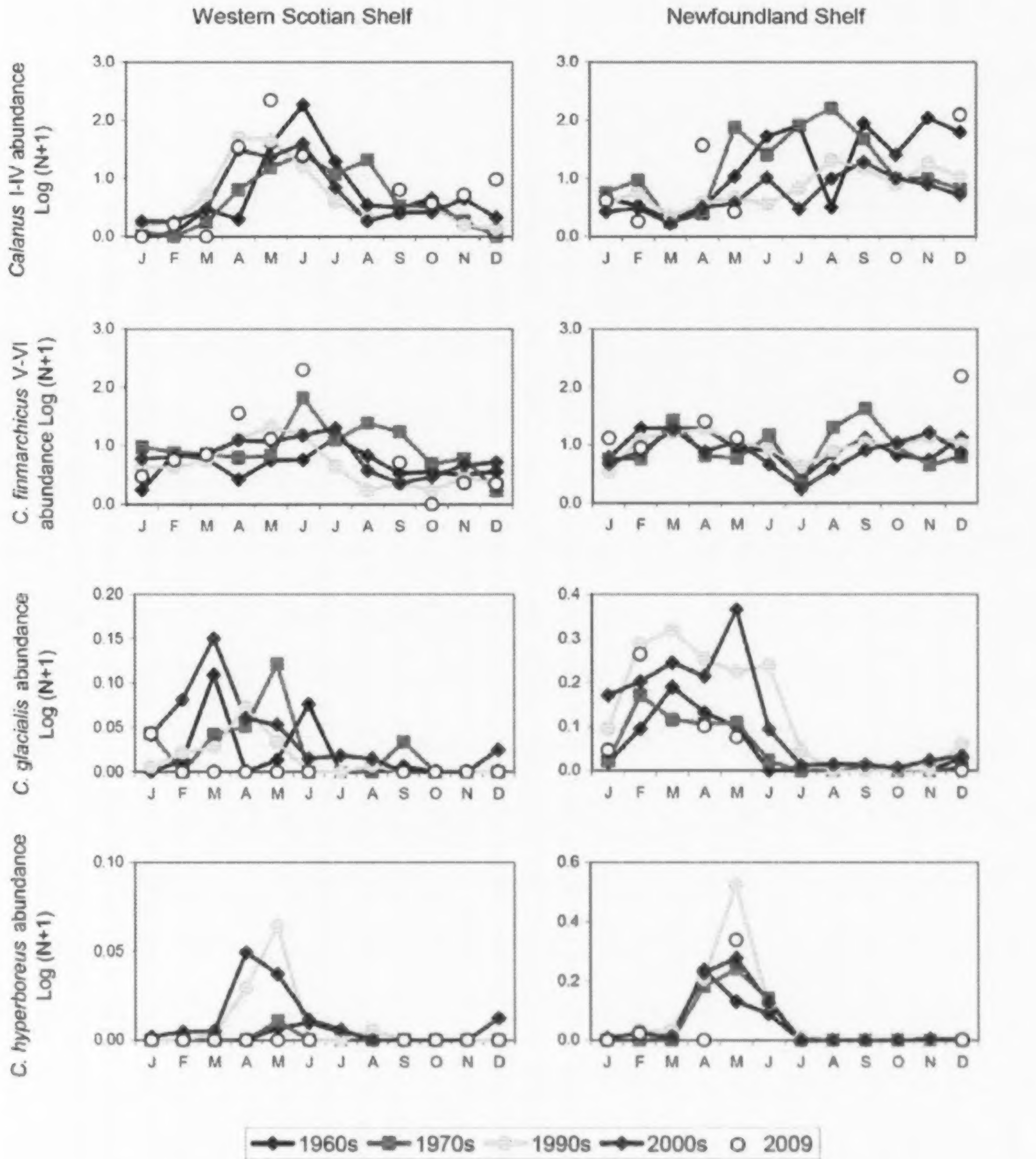


Figure 31. Monthly average abundances of Calanus *taxa on the Western Scotian Shelf and Newfoundland Shelf for the 1960s (1961-1969), the 1970s (1970-1976), the 1990s (1991-1999) and the 2000s (2000-2008). Open circles are values for 2009.*

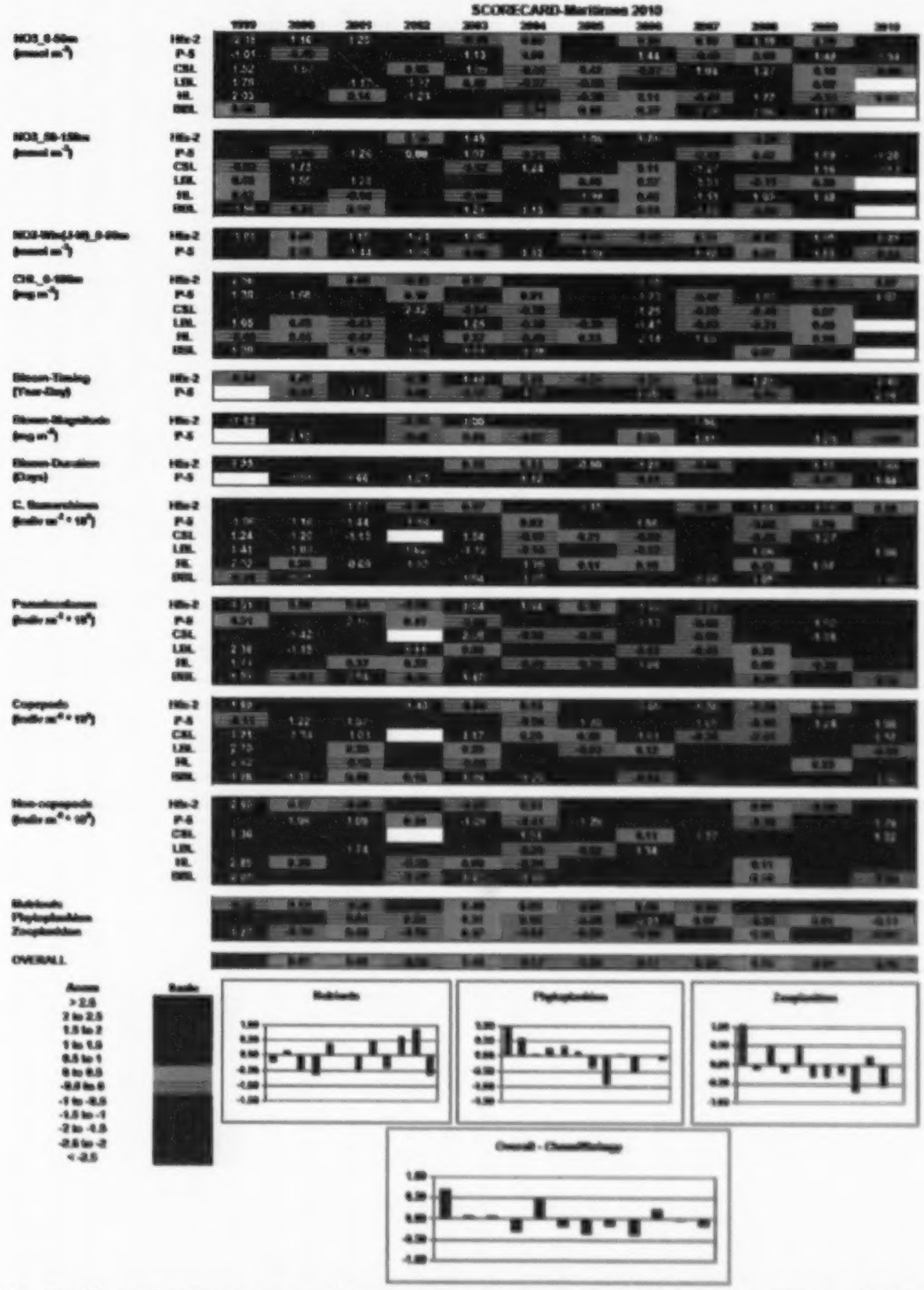


Figure 32. Maritimes Region scorecard: time series of chemical and biological variables, 1999-2010. A white cell indicates missing data. Red (blue) cells indicate higher (lower) than normal nutrient, phytoplankton, zooplankton levels or later and longer (earlier or shorter) than normal duration of phytoplankton blooms. Reference period is 1999- 2008. The numbers in the cells are the anomaly values. CSL: Cabot Strait Line; LBL: Louisbourg Line; HL: Halifax Line; BBL: Browns Bank Line.